
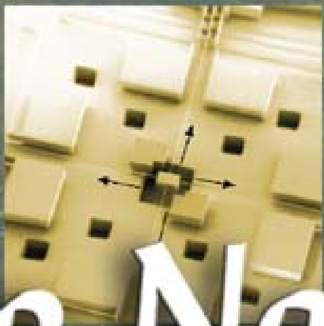


The Nano Coast™

Exploiting the Ultra-Small on California's Central Coast

by

Marshall Burns, PhD

Ennex Corporation

www.Ennex.com

December 2003

A study conducted for

The University of California at Santa Barbara

College of Engineering and

The Center for Entrepreneurship and Engineering Management

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December 2003

Prof. Matthew Tirrell
Dean, College of Engineering
and
Mr. Timothy Schwartz
Director, Center for Entrepreneurship and Engineering Management

University of California at Santa Barbara
Santa Barbara, California

Dear Matt and Tim,

It has been a pleasure over the past several months to meet with your faculty and neighboring businesses to study the opportunities represented by your past and planned investments in nanotechnology research. You truly have a world class organization here, notwithstanding the challenges faced in realizing its potential to the fullest. I hope that questions raised in this study will serve to advance the effort of "exploiting the ultra-small on California's Central Coast."

Best regards,
Ennex Corporation

Marshall Burns
President

Enclosed: *The Nano Coast*

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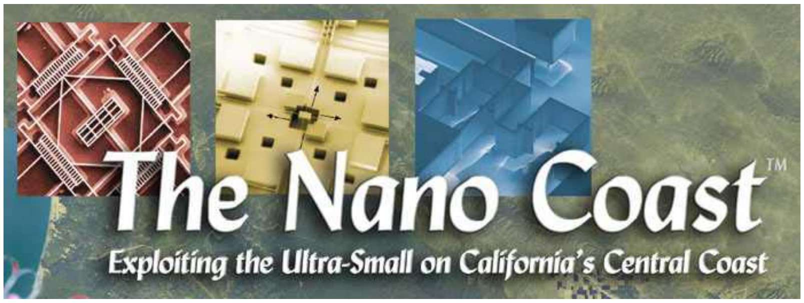

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Executive Summary

Nanotechnology and Santa Barbara. What could one possibly have to do with the other? One is the most advanced technical field known, with products that are too small to be seen by the naked eye. The other is a smallish enclave of wealth and tourism that often looks like a throwback to a bygone era.

But they are connected. In fact, several factors establish the prominence of the Santa Barbara area in nanotechnology research and development:

- The world's first and arguably still most profitable nanotechnology company, Digital Instruments, started in Santa Barbara over 15 years ago and continues to operate in neighboring Goleta as a unit of Veeco Instruments, alongside a number of companies started by former employees. *First nanotech company*
- The University of California at Santa Barbara (UCSB) is home to dozens of world-class scientific faculty conducting over a hundred projects in nanoscience and nanotechnology. *Academic strength*
- The State of California has made $100 million seed investment in the California NanoSystems Institute (CNSI) at UCLA and UCSB. *Government investment*
- Los Angeles, the manufacturing and financial capital of the Western U.S., is 100 miles down the road — close enough for a business deal, but far enough to be "out of sight and out of mind." *Next-door to LA*

This is the ***Nano Coast***, a quiet seaside community harboring a brain trust of world-class scientists and engineers, on the outskirts of one of the world's strongest industrial engines.

This report is the result of a study conducted during 2003 of nanotechnology research and development going on at UCSB and at businesses in the area. The report is organized into three parts:

Organization of report

- ***Background***, discussing the definition of nanotechnology, the geographical region, and the relevant resources that UCSB brings to nanotech research.
- ***Case Examples***, where we look at three projects across the spectrum of realization:
    - Digital Instruments, the successful pioneer in manufacturing of probe microscopes
    - SBA Materials, a recent start-up seeking to exploit new concepts in "biomimetics" emerging from UCSB
    - Spintronics, not yet a company, but a laboratory effort to reengineer the technology of electronics

  In addition, brief descriptions are given of nine other companies in the region with important nanotech aspects, as well as five relevant fields of research underway in various UCSB laboratories.
- ***Challenges and Opportunities***, looking at what it is going to take to exploit the incredible wealth of work going on in this area and turn it into useful products that people pay money for.

Methodology

The study was conducted by research, through public information and personal interviews, of both academic and commercial nanotech projects in the region, seeking to understand (a) their goals, (b) their prospects for success, and (c) the value if they do succeed. This included leading UCSB and affiliated nanoscience and nanotechnology researchers, current companies that are developing nanotechnology, venture capital firms active in this area, and other business leaders.

Key findings

The key findings of the study are found in the three sections of the *Challenges and Opportunities* part of the report:

- <u>CNSI is a force in the nano world.</u> A world class faculty, healthy financial backing, and a powerful board of business advisors combine to create the opportunity to not only make important discoveries, but to then find productive homes for them in the form of commercial products. (See page 29.)
- <u>Tech transfer at UCSB needs beefing up.</u> The Santa Barbara campus is one of the smaller schools in the UC system, but it has a disproportionate potential to generate commercial technology. The infrastructure to move that technology out to the marketplace is missing and needs to be put in place. (page 30.)
- <u>Santa Barbara is a brain trust, not Silicon Valley.</u> The geography and the politics of the region will not support the growth to build an industry hub. Rather, the optimal opportunity for this region is to incubate groundbreaking technology businesses that grow into major enterprises elsewhere. (page 31.)

Who should care?

The intended audience for this report includes three groups:

- Nanotech researchers and companies on the Central Coast that want to see how their work fits into a larger regional context
- Technology investors and entrepreneurs looking to understand the landscape of nanotech opportunities in the region
- Government agencies and private citizens that want to understand the research going on in their communities and consider how it impacts on planning and policy decisions.

The Author

Marshall Burns is a technology entrepreneur and a noted author, speaker, and consultant on advanced technology concepts.

Ennex Companies

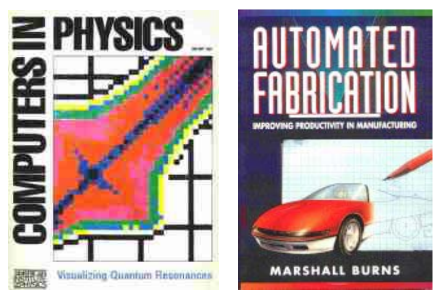
Marshall Burns is the founder and president of the Ennex Companies, a family of ventures dedicated to the development and management of advanced technology concepts. Started in Canada in the 1970s and operating today in Santa Barbara, California, Ennex has been involved in some of the most important technology the world has seen, including PC clone computers, digital manufacturing, Internet software, and nanotechnology.

First PC clones

Research on quantum chaos

Proponent of digital fabrication

In 1982, Marshall Burns Computer Sales, later Ennex Technology Marketing, Inc., was the first manufacturer of "PC clones," which were computers built around the architecture of the famous new IBM Personal Computer. In the late 1980s, Burns' PhD research pioneered in the use of computer color graphics to discern informative patterns in the huge volumes of data arising in physics experiments. This led to the explanation of a puzzling phenomenon in the physics of "quantum chaos." In the 1990s, Burns set a career focus on digital fabrication, a new field of technology for rendering solid objects from digital data and raw materials (also called rapid prototyping or 3-D printing). Ennex Fabrication Technologies produced the first major book on the subject, *Automated Fabrication—Improving Productivity in Manufacturing* (Prentice Hall, 1993) and developed a new process, called "Offset™ Fabbing," which simplifies 3-D fabrication by breaking it up into a sequence of two 2-D steps. Burns has long promoted a vision in which digital fabrication ultimately incorporates nanotechnology to produce all manner of physical products.



Burns' discovery of quantum resonance on the cover of *Computers In Physics* and the cover of his book on digital fabrication

Reputation

Burns has consulted to IBM, Microsoft, Mattel, Disney, 3M, Dow Chemical, Hüls (Germany), the US Navy, the Japanese Rapid Prototyping Association, the United Nations, and many other leading companies and organizations, as well as small and mid-size businesses. His keynote talks have included the First European Conference on Rapid Prototyping (Nottingham, 1992), the Japanese Rapid Prototyping Symposium (Kyoto, 1996), and the Time Compression Technologies Conference (Cardiff, Wales, 2000). He is also the lead inventor on three patents for "Offset Fabbing."

More information on the Ennex Companies can be found at www.Ennex.com. Burns also has a personal Web site at www.MBurns.com.

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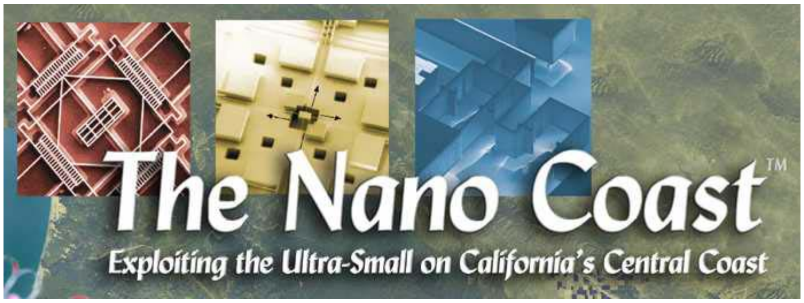

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Background

Part I:
- *What is Nano?*
- *The Central Coast*
- *UCSB*

This initial part of this report lays the groundwork. The first two sections discuss the meaning of "nanotechnology" and establish the geographic region covered in the study. The remaining four sections then look at the University of California at Santa Barbara and three of its nano-relevant research organizations, the Material Research Lab, the California NanoSystems Institute, and the new Institute for Collaborative Biotechnologies.

What is Nano?

Science of the small has a long history

Ever since the days of Zeno and Democritus, people have been fascinated by the mystery of the ultra-small. But it was not until the 1800s that Dalton and Mendeleev laid out the foundation for a consistent atomic theory of matter. Early 20th century chemical researchers, such as Baekeland and Goodrich, created the first synthetic materials, but with limited understanding of the atomic dynamics underlying their discoveries. The advent of computers brought the ability to simulate molecular behavior and eventually the actual design of new molecules, largely driven by the pharmaceutical industry.

In a 1959 speech, *There's Plenty of Room at the Bottom*,[*] Nobel physicist Richard Feynman presented a vision of tiny machines engineered atom-by-atom. Fifteen years later, Norio Taniguchi coined the term "nanotechnology" for a group of methods he proposed could be used to probe and process physical systems at extremely small scales.[†] A paper by Eric Drexler in 1981, *Molecular Engineering*[‡], proposed that it is easier to design new proteins that fold in a predetermined way than to figure out how natural proteins fold into their extraordinarily complex configurations.

Field started to heat up in the late 90s

Nanotechnology began attracting serious interest in academic, government, and eventually financial circles in the late 1990s. Research funding by US federal agencies reached $255 million in 1999.[§] In 2001, the US government launched the National Nanotechnology Initiative (NNI) to coordinate funding across agencies. The president's 2004 budget calls for $847 million for NNI programs.[**] State governments have also been making substantial investments, such as the $100 million seed funds for the California NanoSystems Institute (see page 11). Even venture capital has begun flowing to nanotech start-ups. Of the 91 companies in the portfolio listing for Draper Fisher Jurvetson as of April 2003, twelve were in "Nanotech and MEMS," second-largest out of twelve categories (tied with Wireless; Enterprise Software had 16 companies).[††] CMP Cientifica, a European nanotechnology consultancy, estimates that 33 VC nanotech deals were made worldwide in 2002 with a total value of $249 million.[‡‡]

The next investment bubble?

In the 1990s, with the exorbitant bidding up of Internet investments, there arose a frenzy among technology companies to redefine themselves as "dot coms" in order to attract attention. With the collapse of the Internet "bubble," and with increasing funding available for nanotech, both academic researchers and high-tech companies now have incentive to cast their work in "nano" terms. This has led to new concerns about hype in both academic and business circles. While researchers are loathe to ignore funding opportunities, some actually avoid denoting their work as "nano" for fear of being associated with another over-promoted technology. This makes the challenge of identifying *bona fide* nano research doubly hard: some people are calling their work nano who should not be, and others who could legitimately be using the term do not.

So what is nano, really? The term derives from "nanometer," meaning a billionth of a meter, which is about the size of a sugar molecule. But if nanoscience and nanotechnology just meant working with things that small, the term would quite uselessly subsume most of chemistry and a good deal of chemical engineering, biology, physics, materials science, and several other fields.

Analog to "megatech"

By way of analogy, consider defining the new field of *megatechnology* for development of ultra-large systems and structures. This would encompass the engineering of such things as

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[*] *There's Plenty of Room at the Bottom* by Richard P. Feynman at annual meeting of American Physical Society, 1959 December 29. (www.zyvex.com/nanotech/feynman.html)

[†] *Taniguchi Memorial Lecture* by I. Miyamoto and S. Yoshimoto at MEMStand Workshop, Barcelona, 2003 February 24..26

[‡] *Molecular engineering: An approach to the development of general capabilities for molecular manipulation* by K. Eric Drexler in *Proceedings of the National Academy of Sciences USA*, Chemistry section, Vol. 78, No. 9, p 5275..8, September 1981. (www.imm.org/PNAS.html)

[§] *The National Nanotechnology Initiative*, www.nano.gov/history.pdf, p 12

[**] *NNI R&D Funding in the President's 2004 Budget* (www.nano.gov/fy2004_budget_ostp03_0204.pdf)

[††] *DFJ Portfolio Companies, Edition April 2003* (www.DFJ.com/ourcomps)

[‡‡] *Briefing Nanotechnology* in *Red Herring*, March 2003, p 51

skyscrapers, dams, and space stations, which are understood separately in the domains of architecture and civil and aerospace engineering. The study of megatechnology would look for insights into what is similar and what is distinct about skyscrapers, dams, and space stations. In other words, it would explore the realm at the interfaces of architecture and civil and aerospace engineering that arises when focusing on very large systems.

If someone came along with a new concept that was useful for building skyscrapers but did not carry over to dams or space stations, it might be considered a valuable contribution to architecture, but less relevant to the cross-disciplinary field of megatechnology. On the other hand, if someone later explained *why* the first invention did not apply to dams and space stations, and from that was able to conceive a more general concept that applies across the board to all large systems, that could be an important contribution to megatech.

Not just about smallness — It's about convergence.

As Philippe Busquin, European Union Commissioner for Research, said, "Nanotechnology cannot be defined in terms of dimensions alone. In fact, it represents a convergence of the traditional disciplines of physics, chemistry, and biology at a common research frontier."[*] Nanotech is about what can be learned about small systems that cannot be learned from physics, chemistry, biology, or materials science independently.

Of course, this is not a comfortably objective definition. Furthermore, applying it requires intimate knowledge of all the basic sciences, something few people have. So the fact is that distinguishing between what is nano and what is not is likely to be a fairly controversial subject for some time to come.

Working definition

For the purposes of this study, let us be content to say that we are investigating **opportunities at the ultra-small limits of modern engineering**.

What is it good for?

Nanotech is not just a future technology prospect. It is already used in products available on the market today.

- Eddie Bauer and other clothing manufacturers offer garments made from Nano-Care, a fabric permeated with nanofibers that repel stains and prevent wrinkling.[†]
- French sports manufacturer Babolat reinforces its popular Contender line of tennis racquets with carbon nanotubes for increased rigidity.[‡]
- Wound-care specialist Smith & Nephew markets Acticoat antimicrobial dressings whose silver nanocrystals kill bacteria for up to seven days from time of application.[§]

These are just early examples of what nanotechnology can do. Future applications include ultra-high-speed electronics, targeted drug delivery, and environmental clean-up. Mihail Roco, director of the US National Nanotechnology Initiative, has said that within "a decade or so" products that incorporate nanotech components will comprise a trillion-dollar market, including all computer chips, half of all pharmaceuticals, and half of chemical catalysts.[**]

[*] Philippe Busquin at Joint EC/NSF Workshop on Nanotechnologies, 2000 October 19, quoted at www.cordis.lu/nanotechnology.

[†] *Pleated Nano-Care™ Chinos* (www.EddieBauer.com, search "nano." See also www.Nano-Tex.com, click "Products.")

[‡] *Tennis Rackets*, Babolat (www.Babolat.com/english/tennis/rackets)

[§] *Acticoat™ Dressings* (www.Nucryst.com/index.asp?p=4&s=23)

[**] *Nanotech may aid environment as it alters many major industries* by Jim Krane, Associated Press, 2002 September 9 (http://www.smalltimes.com/document_display.cfm?document_id=4570)

The California Central Coast

Ventura and South Santa Barbara Counties

The 101 corridor

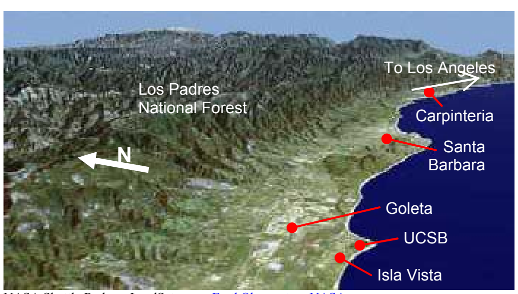
Technically, the Central Coast is that part of the California coastal region between the metropolises of Los Angeles and San Francisco. Much of this is rugged, wilderness territory, dotted with agricultural and tourist communities. This study focuses on the southern part of this region, specifically Ventura and South Santa Barbara Counties. This area encompasses the corridor of Route 101 from UCSB and the city of Goleta (represented on the map below by the neighboring village of Isla Vista) at the northwest corner, extending southeast through Ventura, Oxnard, and Thousand Oaks, where the region merges with the metropolis of Los Angeles.

www.MapQuest.com

The 101 Corridor, comprising the southern stretch of the California Central Coast and extending on into Los Angeles.

Primary focus of study is Santa Barbara area

This is the geographical context of this study. However, we focus here primarily on activities going on in the immediate vicinity of Santa Barbara. The original motivation for the study arises around UCSB, and most companies connected with UCSB that will be of interest here are in Goleta, the Santa Barbara suburb adjacent to the university.



NASA Shuttle Radar + LandSat, www.EarthObservatory.NASA.gov

Santa Barbara Visitors Bureau, www.SantaBarbaraCA.com

Santa Barbara is situated on a rare south-facing stretch of Pacific coastline, backed by over a million acres of federally protected mountain wilderness. With its broad beaches and moderate climate, it is sometimes referred to as "America's Riviera."

Santa Barbara and the adjoining cities of Carpinteria and Goleta lie on a narrow coastal plain sandwiched between the Santa Ynez Mountains and the Pacific Ocean. It is an idyllic environment with a mild climate, breathtaking scenery, and cosmopolitan culture. Traffic on its roads is becoming congested, but is not yet as bad as in most larger cities.

Santa Barbara's roots in oil exploration, aviation, and the Internet

Santa Barbara has a rich history in science and technology. The world's first offshore oil well was drilled in 1887 by H. L. Williams in the waters off of Summerland, a few miles southeast of Santa Barbara.* Brothers Allan and Malcolm Loughead manufactured seaplanes in a factory on State Street in Santa Barbara during World War I. They later changed their name to the more easily pronounce-able "Lockheed" and went on to establish what became one of the world's leading aerospace companies.† Even the world's most famous physicist enjoyed vacationing in Santa Barbara, as seen in the accompanying photograph.

Caltech Institute Archives

Albert Einstein riding a bicycle at the home of friends in Santa Barbara, 1933

In 1963, the prestigious Gordon Research Conferences began its winter series with the Polymers Conference in Santa Barbara. Today, the organization runs 25 to 30 conferences each winter in nearby Ventura. When the ARPAnet, precursor to the Internet, was started in 1969, its initial four nodes included UCSB, due largely to ground-breaking work on computer networking by Prof. Glen Culler. In 1979, UCSB prevailed over 50 other institutions in a proposal to the National Science Foundation for funds to establish an Institute for Theoretical Physics. Renamed in 2002 for a supportive philanthropist, the Kavli Institute for Theoretical Physics hosts leading physicist from around the world for conferences and other programs on cosmology, elementary particles, biophysics, and other cutting-edge topics.

UCSB as a Research Organization

The University of California at Santa Barbara is not only the intellectual focal point of the California Central Coast, it is a preeminent research institution in its own right.

UCSB brings 19,000 students and 1,100 faculty and researchers together on a 1000-acre Pacific Ocean promontory on the outskirts of Santa Barbara, approximately 100 miles northwest of Los Angeles.‡ An idyllic location for either surfing or intellectual discourse (or both), the school has been honored with three Nobel prizes in the last five years. Approximately 3,800 undergraduate (21%) and one thousand graduate (42%) students are enrolled in the technical departments of the university (mathematics, physical and life sciences, and engineering).

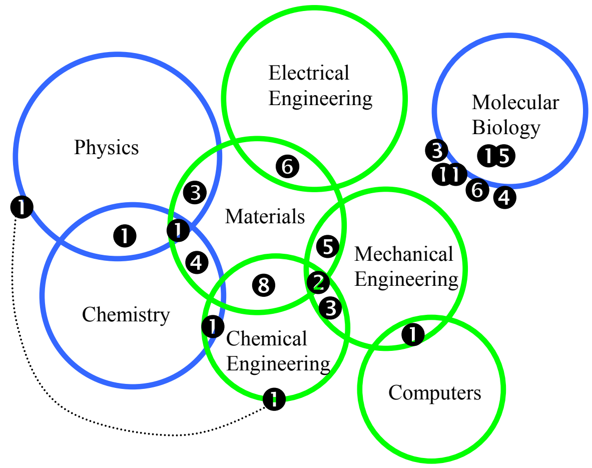
* *History of Offshore*, National Ocean Industries Association (www.NOIA.org/info/history.asp)

† *History*, Lockheed Martin Corporation (www.LockheedMartin.com/about/history.html)

‡ Population and land area from *2000 – 2001 Campus Profile* and *2001-2002 Undergraduate Information Guide*, University of California at Santa Barbara (http://bap.ucsb.edu/IR/IRPpub.html). Populations figures include only full-time students, and academic staff. They are supported by an additional 2,300 full-time non-academic staff and 2,500 non-student part-time staff.

Interdisciplinary culture

UCSB is known for its interdisciplinary research culture. Of 240 faculty in the physical sciences and engineering, 36 have joint appointments in two, or even three, departments.* As if to acknowledge the creative insights that arise from such cross collaboration, the three recently-awarded Nobel prizes have been in subject fields different from the formal faculty affiliations of the winning professors. The 1998 prize in chemistry went to physicist Walter Kohn, the 2000 physics prize was awarded to Herb Kroemer, professor of electrical engineering and materials, and Alan Heeger, professor of physics and materials won the 2000 chemistry prize. After this award, Heeger added chemistry to his official affiliations, becoming one of three faculty members to have simultaneous appointments in three different departments.



Overlapping appointments in UCSB's physical science and engineering departments. The numbers for Molecular Biology indicate the indirect connection, via the Biomolecular Science and Engineering Program, of 15 of its faculty to faculty in the Physics, Chemistry, Materials, and Chemical Engineering Departments.

Top rankings nationally

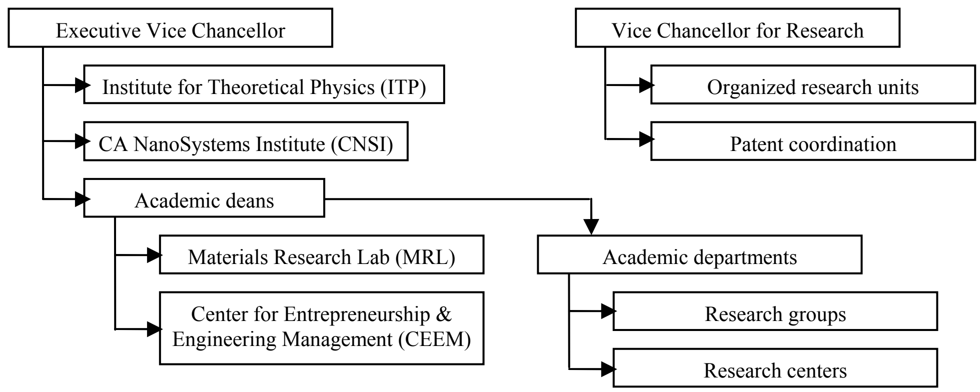
In the *Science Watch* "Top Ten Tournament" of highest-impact US universities from 1998 through 2002, UCSB ranked #1 in materials science, #2 in engineering science, and #7 in each of physics and chemistry.

Not a wealthy school

Notwithstanding its world-class faculty and its location near affluent Santa Barbara, UCSB is not a wealthy school, even just compared to other schools in the nine-campus University of California System. The total budget for fiscal 2001 was just over $400 million for UCSB, while five other UC campuses had budgets exceeding $1 billion. By this measure, UCSB ranks 7th out of nine campuses, or 8th if the numbers are compared on either a per-student or per-faculty basis. The value of UCSB's endowments in June 2001 was only a little under $90 million, compared to three campuses with endowments close to or exceeding $1 billion. Even by research expenditures, UCSB is a small school. This measure for UCSB in 2001 was under $100 million, at $350,000 per science and engineering faculty member. Four other campuses in the system had research expenditures exceeding $300 million, all exceeding $500,000 per technical (science, engineering, and medical) faculty member.† (See *Vital Statistics of Universities,* page 39, for a table of these and other data.)

* Joint appointment data from analysis of faculty listings on department Web sites as of 2003 March 8. Emeritus faculty are excluded from the counts. In the figure, colors represent colleges, green for Engineering, blue for Letters and Science.

† Fact sheets for all UC campuses (www.UniversityOfCalifornia.edu/campuses/welcome.html)



The organizational structure of technical research at UCSB. Many professors conduct research under multiple affiliations, with laboratories organized both within and across the lines of academic departments.[*]

Research organization

In addition to having joint appointments across multiple academic departments, many faculty perform their research within multiple organizational structures. The simplest structure is the *research group*, usually consisting of a single professor together with student and post-doctoral researchers. A *research center* usually involves several professors, together with their researchers, often from more than one department but administered under a particular department. An *organized research unit* is an interdisciplinary collaboration that spans multiple departments and is administered under the vice chancellor for research. Research laboratories or institutes that are large enough to have their own buildings (ITP, MRL, CNSI) are administered directly by an academic dean or by the executive vice chancellor of the university.

Most professors, while operating their own research groups, also either lead or participate in one or more research centers, organized research units, and/or major institutes. These multiple affiliations can make it quite difficult for both the outsider and newly arrived faculty to make sense of who is doing what, where. It makes the university a complex system, where the creative output of one professor or graduate student can be multiplied by cross-pollination into applications in seemingly unrelated academic and technical disciplines.

Technology transfer

Intellectual property of the university is managed by a patent coordinator working under the vice chancellor for research, in conjunction with the Office of Technology Transfer of the University of California System, UCSB's parent body in Oakland. The latest published figures[†] show UCSB having a portfolio of 290 inventions, with 81 new disclosures in the most recent year. This portfolio included 141 active US and 68 active foreign patents, for which there were a total of 19 active license agreements and 10 active licensing options. (See *Tech Transfer at UCSB*, page 30.)

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[*] *2002-2003 UCSB Organizational Charts* (http://bap.ucsb.edu/IR/orgcharts/charts0203.html)

[†] *UC Technology Transfer — Annual Report 2001*, University of California (www.UCOP.edu/ott/ars/ann01/ar01.pdf)

Promoting entrepreneurship

The Center for Entrepreneurship and Engineering Management (CEEM) is an initiative started within the College of Engineering to promote both commercialization of university technologies and local entrepreneurship regardless of university affiliation. The Center is developing academic programs on business management and entrepreneurship designed to assist students and faculty in spinning off promising technology to the marketplace and to assist other entrepreneurs in the community to build successful technology businesses. An important part of this program includes frequent events that foster interaction between the university (both faculty and students) and the local business and financial community.

Successful spin-offs

A number of UCSB faculty and students have started successful entrepreneurial ventures, some of which are profiled in later sections of this report. For example, Digital Instruments (see *The Probe Microscope*, page 15), a microscope manufacturer started in 1986 by physicist Virgil Elings, was acquired by Veeco Instruments in 1998 for $219 million. A Materials Research Lab seed project by Steve DenBaars and Umesh Mishra on electro-optics in gallium nitride (see *Optoelectronics*, page 26) led to the creation of Nitres in 1996, which was purchased by Cree in 2000 for $210 million. That same year, also the year in which Alan Heeger won the Nobel Prize for conductive polymers, DuPont paid $30 million for Uniax, a company started by Heeger in 1990 to develop commercial technologies based on such materials (see *Conductive plastics*, page 26).

Nano Coast Players — Technology Development at UCSB

- Acting Executive Vice Chancellor (www.EVC.UCSB.edu): **Glenn Lucas**
- Office of Research (Research.UCSB.edu):
  - **Steven Gaines**, Acting Vice Chancellor
  - **Sherylle Englander**, Patent Coordinator
- College of Engineering (www.Engr.UCSB.edu):
  - **Matthew Tirrell**, Dean
  - Center for Entrepreneurship and Engineering Management (CEEM.Engr.UCSB.edu): **Timothy Schwartz**, Director
- Division of Mathematical, Life, and Physical Sciences: **Martin Moskovits**, Dean

Materials Research Lab

With the interdisciplinary culture of UCSB, it is perhaps fitting that one of its largest free-standing laboratories is devoted to research on materials. The study of materials cuts across many fields of traditional science, (e.g. chemistry, physics, biology, geology) and engineering (e.g. chemical, electrical).

The origins of modern materials research can be traced back to Russia's launch of the Sputnik satellite in 1957, or more specifically to the U.S. reaction to it.* Recognizing the importance of novel materials to any anticipated space program, the Defense Department established a chain of twelve university laboratories to focus on this issue. They were called, appropriately enough, the Interdisciplinary Laboratories (IDLs). A decade later, management of this research program was transferred from Defense to the National Science Foundation (NSF) and the name was changed to the Materials Research Laboratories. The MRLs conducted research of a scope and complexity that required the advantages of scale and interdisciplinary interaction not typically available in individual research centers or small groups. They also developed state-of-the-art shared facilities for use by other universities and industry.

DoD's IDLs …

… became NSF's MRLs …

Shortly after being recruited away from Oxford in 1991, Prof. Anthony Cheetham joined in on a proposal to establish an MRL at UCSB. When the proposal was accepted the next year, the university asked him to be director of the new organization. Cheetham has managed the lab since that time, although he recently announced his intention to step down and a search is underway for a new director.

In 1994, NSF transformed the network of MRLs into Materials Research Science and Engineering Centers (MRSECs), with an expanded scope.† In addition to high-level research and shared-use facilities, the MRSECs are chartered for both educational and industrial outreach. Educational outreach is intended to make materials research accessible to teachers, to undergraduate and pre-college students, and to the general public. Industrial outreach includes both "knowledge transfer," in which technical advances are discussed freely between the MRSECs and industry partners for mutual benefit, and "technology transfer," in which more formal arrangements provide for collaborative development of valuable intellectual property.

… which became the MRSECs.

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* *A Never-Ending Search for the New and Useful* in *America's Investment in the Future*, National Science Foundation, 2000 (www.NSF.gov/od/lpa/news/publicat/nsf0050/materials/search.htm)

† *Up Close: Materials Research Science and Engineering Centers—U.S. National Network for Materials Research* by Clyde L. Bryant in *MRS Bulletin*, v 27, #8, p 637, August 2002 (www.MRSEC.org/home/Aug02_UpClose.pdf)

Funding for UCSB's MRL is 3rd in nation, after the two oldest labs in the system.

UCSB's MRL has risen to be one of the most prominent MRSECs in the country. Back in 1960, the first two IDLs to be established were at Cornell University and the University of Pennsylvania.† Thirty-two years later, there were nine MRLs in the NSF program when UCSB entered the field. By 2003, the number of MRSECs has climbed to 29. Each competes every five years for continuation funding based on the intellectual merit and potential impact of ongoing and proposed new activities. Funding awarded to the centers ranges from $600,000 to $4 million per year. Currently, the MRL at UCSB receives $3.3 million annually from the NSF, the third highest level of funding in the system, behind only old-timers Cornell and Penn.‡ The NSF funds are augmented by about $1 million in other government and industrial grants and gifts and $700,000 from the university, bringing the total laboratory budget to $5 million per year.

Artificial cell membrane assembled from protein (blue/purple) and fat (orange) molecules by UCSB MRL scientist Cyrus Safinya may have applications as diverse as drug delivery and templating of metal nanotubules for electronic devices.*

The MRL's research is currently conducted by about 35 UCSB faculty from eight academic departments (five science and three engineering).§ Many additional UCSB faculty take advantage of the laboratory's facilities as external users. Many projects are conducted in collaboration with scientists from outside organizations – 45 universities in thirteen countries, 25 industrial companies, and three government labs. Research is assisted by 75 graduate students and post-doctoral researchers plus 30 undergraduate interns. Some of this work is conducted in the 14,000-square-foot MRL building that opened in 1997. A 7,000-square-foot expansion is planned for completion in late 2004.

A lot of the research is "nano."

When the IDLs were established in the 1960s, much of materials research was conducted at the bulk scale, observing and seeking to influence the behavior of materials on the basis of macroscopic properties. In contrast, today's tools often allow researchers to both investigate and manipulate materials at the molecular level. Therefore, much (or most, depending on definitions) of the MRL's research lies in the realm of "nano." The faculty of the laboratory each work in one or more of four research groups with the following foci:

- **Biomaterials.** Microstructures made from biological materials (see, e.g., above figure of artificial cell membrane)
- **Solution synthesis.** Mechanisms for formation of various inorganic materials, such as biominerals (see, e.g., *Biomimetics*, page 18), porous materials, and thin films
- **Mesoscopic assemblies.** Synthesis, simulation, and applications of *block copolymers*, a class of materials with an interesting and useful cross of characteristics of fluids and crystalline solids

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* *Hierarchical Self-Assembly of F-Actin and Cationic Lipid Complexes: Stacked Three-Layer Tubule Networks* by Gerard Wong, *et al.* in *Science* v. 288, p. 2035, 2000 June 16

† *Materials Research Laboratories: Reviewing the First Twenty-Five Years* by Lyle H. Schwartz in *Advancing Materials Research*, National Academies Press, 1987 (www.NAP.edu/html/materials_and_man/0309036976/HTML/35-48.HTML)

‡ NSF FastLane system (www.FastLane.NSF.gov/servlet/A6QueryPgm)

§ *Annual Continuation Report*, Materials Research Laboratory, UCSB, March 2003

- **Complex phenomena.** Behavior of materials with complex molecular structure or interaction under special circumstances, including such phenomena as fracture, drop formation, and lubrication

Nano Coast Players — Materials Research Laboratory (www.MRL.UCSB.edu)
- **Anthony Cheetham**, Director (outgoing)
- **Edward Kramer**, Chair of search committee for new director

California NanoSystems Institute at UCSB

In his *State of the State* address in January 2000*, Governor Gray Davis announced an initiative to launch the California Institutes of Science and Innovation, a collection of new research centers to be created on campuses of the University of California. The plan, as later spelled out, called for providing $100 million of seed funding to each institute over four years, with the host universities committing those funds to be matched two-to-one by non-state sources. A competition was launched for proposals from UC campuses for institutes under the program.

$100 million to seed nanotech partnership between UCLA and UCSB

At the end of that year, Davis announced the first three successful candidates in the competition.† One was the California NanoSystems Institute to be established as a partnership between the UC campuses at Los Angeles and Santa Barbara. By February 2003, $138 million of the $200 million matching funds had been committed by federal agencies, private industry, and foundations.‡ The provided funds are primarily allocated to the construction of two new buildings on the UCLA and UCSB campuses. These buildings will house the two branches of the institute and provide laboratory and office space for affiliated faculty.

CNSI is the brainchild of a number of visionaries on both campuses. Administrative leaders were UCLA's vice chancellor for research and former professor of physics Roberto Peccei and UCSB's dean of engineering and professor of materials and chemical engineering Matthew Tirrell. The founding scientific directors were UCLA professor of chemistry James Heath and UCSB professor of materials and electrical engineering Evelyn Hu. For founding executive director, the team recruited Martha Krebs, the former U.S. assistant secretary of energy and director of the Office of Science in the U.S. Department of Energy.

A rocky start

The establishment of this new organization has not been entirely smooth. After moving to Los Angeles for the directorship in 2001, Krebs left the position abruptly the following January. Two

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* *State of the State* by Governor Gray Davis at State Capitol, Sacramento, California, 2000 January 15 (www.ca.gov, select "Governor," then "Speeches," then "2000")

† *Governor Davis announces locations of three Institutes for Science and Innovation*, Office of the Governor, Sacramento, California, 2000 December 7 (www.ca.gov, search "institutes for science")

‡ *Governor Gray Davis breaks ground at new cutting-edge technological institute*, Office of the Governor, Sacramento, California, 2003 February 14 (www.ca.gov, search "institutes for science")

months later, Heath announced that he was leaving UCLA for Caltech. Despite the setbacks, the institute has moved forward under the joint leadership of Hu and UCLA chairman of chemistry Fraser Stoddart. Ground was broken for the buildings in 2003, at UCLA in February and at UCSB in October.

Management at UCLA

A number of important developments in the management of the institute took place in 2003. UCLA's Fraser Stoddart was selected to be the interim director until the buildings are completed, after which a search for a new director may be launched. Derrick Boston was recruited as senior vice president to work on corporate alliances and venture spin-offs. Boston is a former Irell & Manella attorney, was a senior VP for investment banker Digital Coast Partners, and most recently was CEO of internet start-up Timeskeeper.com.

Business Advisory Board

Six months after Boston's arrival, CNSI announced the formation of its business advisory board.* Industrial members include executives and senior researchers from IBM, General Electric, Dupont, Intel, Eastman Chemical, and other major companies with significant interests in nanotechnology. Investor members include partners or executives from Draper Fisher Jurvetson, Eastman Ventures, JPMorgan, Bear Stearns, Sevin Rosen, the California State Teachers' Retirement System, and other major funds. This is an important development because, if managed well, the industrial and investor contacts can create a natural avenue for licensing and business start-up activity.

For the Central Coast region, the establishment of CNSI represents much more than just another building at UCSB. Like the MRL before it, CNSI is an institution ideally suited for the interdisciplinary culture of the university. Many of the projects discussed in this report have been going on at UCSB for years, since long before CNSI was conceived. They are diverse in their core disciplines, yet all are connected by their nanoscale aspects. Some of their participants have been aware of each other before and some have collaborated on related issues. CNSI provides a center of gravity for such diverse projects to orbit in a unified context. It's an opportunity for cellular biologists to learn from work in heterogeneous semiconductors, for developers of atomic-scale microscopes to learn from the chemistry of heterogeneous catalysis.

Interdisciplinary interaction

The first taste of this cross-collaboration is beginning to be felt in the weekly "brown bag" seminars held in the conference room of the institute's temporary UCSB quarters. Here researchers come not just for a talk on device electronics, membrane physics, or bacterial biochemistry, but for any of the above in the context of how to conduct research in the realm of the ultra-small. Like the Materials Research Laboratory founded ten years earlier, the magic of the CNSI is that it is not an academic department, but brings together researchers from diverse departments to share and combine their expertise to solve frontier problems in a new field of investigation.

Research structure

The proposal to the governor that became the charter of the Institute laid out four main topics of investigation:

- **Nanostructures**, the "building blocks" of nanosystems, such as bio-inspired structures (see page 18), quantum dots (page 26), and magnetic semiconductors (page 22)
- **Molecular medicine**, including studies in structural and computational biology and biological nano-machines
- **Information technology**, including memory and logic (see, e.g., *Spintronics*, page 21), data transmission (e.g., *Optoelectronics*, page 26), and interfaces

* *Business Advisory Board*, CNSI (http://cnsi-uc.org/people/advisory.html)

- **Infrastructure**, the tools and basic techniques that will underlie discoveries in the above topics, such as analytics, imaging, and modeling

See the appendix (page 38) for a listing of the specific projects attributed to UCSB faculty under each of these topics in the proposal.

Nano Coast Players — California NanoSystems Institute (www.CNSI.UCSB.edu)
- **Fraser Stoddart**, Executive Director (at UCLA)
- **Evelyn Hu**, Scientific Director

Institute for Collaborative Biotechnologies

$50 million for UCSB partnership with Caltech, MIT

In August 2003, the U.S. Army announced the award of $50 million over five years to establish a new Institute for Collaborative Biotechnologies (ICB). The institute will be headquartered at UC Santa Barbara as a partnership among UCSB, the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT).

Bio closely tied to nano

Biotechnology has a lot of crossover with nanotechnology. Most biological processes function and are controlled at the nanoscale. A lot of research in nanotechnology is conducted with one eye (or more) on nature for hints on how to make a molecule do something. So it is not surprising that of the 36 UCSB faculty identified with the ICB in the original proposal, 25 of them are members of the CNSI. Twelve of them are also members of the Materials Research Lab.

Areas of focus

The aim of the ICB is to use the fundamental molecular and cellular mechanisms that are responsible for the high performance of biological systems to develop biologically inspired new technologies for:

- **Sensors** to detect poisons, bacteria, and viruses that may arise from biological weapons, industrial accidents, or natural disease
- **Electromagnetic materials.** Materials with special electrical, optical, or magnetic properties that enable smaller, lighter, and more powerful computers, portable lighting, radio devices, and batteries
- **Information processing.** Technology for computation and telecommunications inspired by how electrical signals are communicated and interpreted in living cells

The ICB is organized into six research teams. One each works on the three technology areas above. The remaining three teams work on the underlying tools that drive the success of the first three. These include methods for discovery of biological processes, imaging and inspection devices, and computer modeling techniques. Many members of the ICB faculty work on two or even three of these teams, so there is a lot of cross-collaboration.

Most of this kind of work is conducted at the nanoscale. So a good deal of the output of the ICB can be expected to be or contribute to nanotechnology.

Nano Coast Players — Institute for Collaborative Biotechnologies

- **Daniel Morse**, Director
- **Frank Doyle**, Associate Director
- **Alan Heeger**, Chair, Scientific Advisory Committee

Case Examples

This middle part of the report looks at several nanotechnology projects on the Central Coast. Most of this section is dedicated to three examples across the spectrum of realization, from a company that was started over 15 years ago, to another that is just now getting off the ground, to UCSB research that may yet be 15 years away from commercial exploitation. Also considered are some third- and fourth-generation nanotech offspring companies, some other UCSB research, and a few companies in the area that did not come out of UCSB.

Part II:
- *Digital Instruments*
- *SBA Materials*
- *Spintronics*
- *DI Offspring*
- *Other Projects*

Established Success: Digital Instruments

The Probe Microscope — Flashlight and Pick-Axe of the Nano Rush

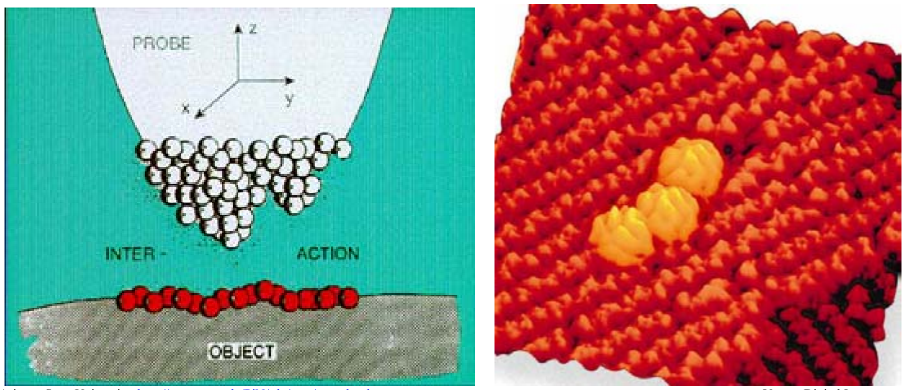
In a gold rush town, the smart money is behind the hardware store. While its customers are falling over each other in fierce competition to find the next glittering vein, the purveyor of flashlights and pick-axes reaps a steady stream of profits from the endeavors of winners and losers alike. In the "nano" rush, there is a technology that has turned out to serve the role of both flashlight and pick-axe for our molecular quarry. It is the probe microscope.*

Enabling tools are a critical — and profitable — part of an industry

In the 1970s, when "nano" was more commonly associated with Robin Williams than Eric Drexler, UCSB high-energy physicist Virgil Elings was running a graduate program on scientific instrumentation that he created. It was a propitious time, as the science of microscopy was about to undergo a revolution. Ever since its origins in ancient magnifying glasses, the microscope had always worked in the same way that people normally see — by illuminating an object with some form of radiation (originally light, later electrons) and watching for how the radiation is reflected or transmitted. But in 1981, IBM researchers turned to the technique used by blind people — reaching out to feel a surface with a finger or stick. Using exquisite control of an ultrafine needle-tip, a probe microscope can produce surface images with brilliant, atomic-scale resolution.

"Seeing" by feel, rather than by illumination

* Tech talk: Probe microscopes are more formally called *scanning probe microscopes* (SPMs) and come in two primary flavors. The *scanning tunneling microscope* (STM) watches the behavior of a minute electric "tunneling" current passing between the probe and the object being inspected. In the *atomic force microscope* (AFM), the probe feels for the same atomic forces that keep solid objects from passing through each other.



Arizona State University, http://acept.asu.edu/PiN/rdg/spm/spm.shtml Veeco–Digital Instruments

Probe Microscopy. The schematic illustration on the left shows atoms on the tip of a probe that interact with atoms on the surface of the object. Instrumentation analyses the interactions to form an image of the surface. The example result on the right shows, at 5 million times magnification, three spherical carbon molecules lodged in the surface of a silicon crystal. Each orange mound in the image is a carbon atom, while the red shapes are silicon atoms.

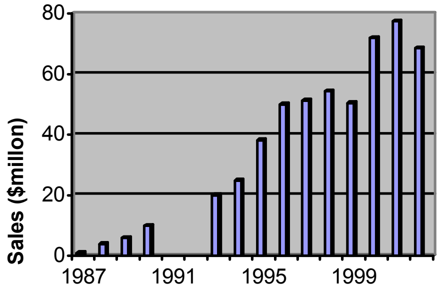
Establishment of Digital Instruments

Six years after the invention of probe microscopy, and the year after its inventors shared the Nobel Prize in physics, Elings left UCSB. With some of his former students and with an investment of $50,000, he started a new company, Digital Instruments (DI), to put one of the first commercial probe microscopes on the market. The NanoScope® became an instant success, selling more than 300 units at about $70,000 each in the first four years.

Another physicist, Paul Hansma, has also played an important role in the company over the years. Hansma remained at UCSB, where he conducts groundbreaking research on probe microscopy, some of which has been licensed to DI.

Seeing by feel also allows manipulation

An important feature of probe microscopy is that, like a blind person "seeing" with his fingers, the probe can not only see what is there, but can push on it if desired. This is how the probe microscope has become both the flashlight and the pick-axe of nanotechnology. It allows researchers to both see individual atoms and to move them from place to place.



Growth of Digital Instruments was exponential up until the year before its acquisition, but has been sporadic since then.*

In retrospect, it's easy to see how smart a market move it was to make a probe microscope in 1986. The concept was still new, and building such a microscope was a significant research effort in itself. Yet scientists of all stripes, from geology to neurobiology, have a perpetual, driving need to see at finer and finer scales. The NanoScope allowed these scientists to concentrate on their own research without becoming mired in the complexities of building a microscope. Yet, while those complexities are daunting at the design stage, probe microscopes are not very expensive to manufacture. So the resulting products turned out to be very profitable. In the five years before its acquisition, Digital's gross profit margins were consistently between 50% and 57%. Net income was even more impressive, ranging from 25% to 32% over the same period.

Highly profitable

DI was so profitable that it never had to go outside for investment. When the company was acquired by Veeco Instruments in 1998 for $219 million in stock, Virgil Elings and his former student John Gurley owned 97% of the company. As a result, they fared far better than most high-flying Internet entrepreneurs whose companies sold for multiple billions of dollars after multiple rounds of stock dilution.

Digital Instruments has maintained its founding leadership in commercial probe microscopes. While the name lives on today as a Veeco product line, its microscopy business now spans two Veeco divisions and owns about $^{2}/_{3}$ of the global market for probe microscopes. Still operating in the Santa Barbara suburb of Goleta, the number of employees has grown from 130 at the end of 1997 (just prior to the acquisition) to just under 300. While Elings has moved on to other ventures (e.g., see *Higher-Generation Offspring*, page 24), Hansma continues (upon resolution of some previous licensing disputes between the university and Veeco) to conduct research important to the development direction of the company.

New developments

Veeco has launched a number of new products that expand the applications of probing technology beyond microscopy. These instruments focus on molecular manipulation, sensing, and force measurement. Within microscopy, one of the improvements on the horizon is high-speed imagery. In 2003, the fastest commercially available probe microscopes can take a minute or longer to form an image. Technology currently under development will boost this to ten images per second, allowing researchers for the first time to observe the atomic behavior taking place in biological and other physical processes.

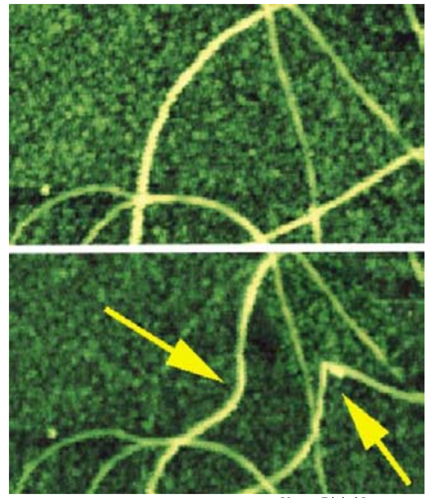
* Sources of sales data:
- 1987..90: Estimated growth curve based on selling 300 NanoScopes at $70,000 each in those years [*Economist*, 1993, as quoted by Baird and Shew, 2002]
- 1993..98: Veeco proxy statement of 1998 May 9 and 1998 annual report
- 1999..2002: 45% (percentage represented by DI at time of acquisition) of Veeco's annually reported metrology sales. This is the best estimate available from public information. Company declined to provide alternative data, such as sales for the Santa Barbara operation less the Dektak Division, which would likely be both more favorable and a better representation of the growth of DI since the acquisition.

Hansma lab

In addition to developing state-of-the-art microscopy that often finds a home in Digital Instruments' products, Hansma's lab also serves as something of a service bureau for other UCSB faculty needing a set of nano-eyes for their research. In particular, Hansma is a frequent collaborator with Dan Morse, Galen Stuckey, and their colleagues in studies of biomaterial synthesis (see *Biomimetics* below). Another frequent collaborator is Hansma's former wife, Helen Hansma, whose research focuses on imaging of biological materials.

Offspring companies

Since the Veeco acquisition, at least four nanotechnology companies have been started by former employees of Digital Instruments or its progeny. Two of them, Asylum Research and MultiProbe, make probe microscopes. The other two, Atomate and First Nano, make different kinds of tools for nanotech research. See *Higher-Generation Offspring* on page 24 for brief information about these companies.



Veeco–Digital Instruments

Manipulation of carbon nanotubes with Veeco's new NanoMan System. The arrows indicate where force has been applied to move the tubes between the upper and lower images. 60,000 times magnification.

Nano Coast Players — Probe Microscopy

- UCSB: **Paul Hansma**, Physics (HansmaLab.Physics.UCSB.edu)
- Veeco Instruments, Digital Instruments product line (www.Veeco.com/html/product_bymarket_research.asp):
  - **Ken Babcock**, VP and GM, Research Products Division
  - **Lloyd LaComb**, VP and GM, Semiconductor Metrology Division
- Asylum Research (www.AsylumResearch.com): **Jason Cleveland**, Chairman; **Roger Proksch**, President
- MultiProbe (www.MultiProbe.com): **Andrew Erickson**, President

Up and Coming: SBA Materials

Biomimetics — Learning from Life

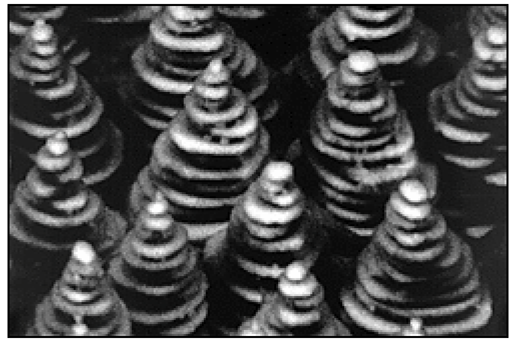
Mimicking biology

One of the first things one notices when getting into nanotechnology is that what we want to accomplish in it has been underway in biology for millions of years. The very process of life itself, whether plant or animal, involves the manipulation of raw materials at their molecular level to exchange energy, build structures, and record or retrieve information. *Biomimetics* is the search for artificial techniques that mimic the magic of biology.

A powerful collaboration began one day when Galen Stucky, a UCSB chemist and materials scientist, visited the office of molecular biologist Dan Morse. When Morse described his work on the biological synthesis of nacre, the pearl-like inner lining of seashells, Stucky smiled and asked, "Have you ever thought of this stuff as a material?" The two researchers joined forces and, along with other collaborators at UCSB and elsewhere, have produced a rich body of work on biomimetic materials, including forming a company to commercialize some of their concepts.

3,000-times tougher material through protein-guided growth

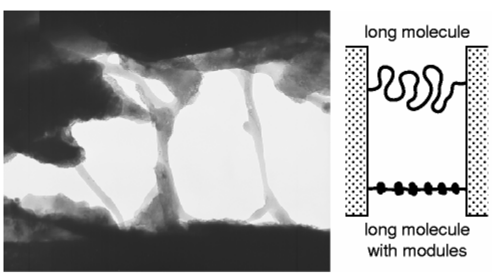
Nacre, it turns out, is a fascinating material. Beautifully iridescent, it is also very tough (fracture-resistant). The primary component is aragonite, a crystalline form of calcium carbonate ($CaCO_3$) which, by itself, is fibrous and brittle. But marine creatures, such as abalone, have developed a masonry-like structure of microscopic aragonite flakes cemented together in a soup of proteins secreted by the growing animal. The proteins form a regular pattern of nanometer-sized pores that act as a stencil through which grow crystals of aragonite. From this process comes a highly uniform structure with a tightly embedded organic matrix. The resulting nacre is three thousand times tougher than the mineral form of aragonite.



Micrograph of abalone nacre, showing growth of aragonite crystal that forms the bulk of the material, guided by a protein structure of nanoscale pores.

How useful would it be if industrial manufacturing could mimic this procedure for producing tough materials that resist breakage? The problem is that seashells take a long time to grow. A layer of nacre in abalone typically grows only about five microns (about one-tenth the thickness of a human hair) per day. At that rate, even a small product like a golf putter, say ¼-inch thick, would take 3½ years to grow. So the UCSB team has been testing artificial techniques to produce a nacre-like structure much faster.

Self-healing glue



Adhesive ligaments in abalone nacre stretched to 20 times their relaxed length and still holding together two aragonite platelets. The sections of ligament seen in this 50,000 times magnification are as narrow as 10 nm. On the right is a schematic illustration of long molecules whose folds are free (top) and bonded (bottom). The latter models the operation of the abalone ligaments.*

In the course of this research, another interesting discovery was made by collaborating scientist Paul Hansma and his group. A probe microscope (see page 15) was used to tug at the microscopic aragonite flakes in cleaved slivers of nacre. When this was done, the protein glue between the flakes would stretch and pop, stretch and pop, stretch and pop, repeatedly. While the precise mechanism is not yet fully known, it appears that when stretched to a certain limit, the protein lets go of chemical bonds holding it in a certain folded configuration. The breaking of these bonds releases tension in the stretching of the molecule, preventing the molecule itself from breaking. The proteins can undergo several cycles of stretching and popping without breaking down. And if the molecule is allowed to relax, the folding bonds can reform, returning the structure to its original condition. This is, in essence, a self-healing glue. It can not only withstand, but even recover from, a severe stretching when the bonded components are pulled apart.

* *Molecular mechanistic origin of the toughness of natural adhesives, fibres and composites* by Bettye L. Smith *et al.* in *Nature*, v 399, 1999 June 24, p 761..3

No wonder nacre is so tough! And therein lies another challenge for biomimetics researchers. Imagine an adhesive with the strength of epoxy that stretches like a rubber band when stressed, and then returns to a rigid state when released. Imagine a rubber band that, when stretched past its limit, does not break, but instead pops and continues stretching to another limit. This could be the beginning of a whole new class of materials with heretofore unimagined endurance and flexibility.

SBA Materials founded to exploit opportunities

It's one thing to discover how nature performs her magic. It's quite another to conceive ways to imitate her artificially. Biomimetic adhesives and elastics are an alluring long term objective. But Stucky and Morse, along with UCSB chemical engineer Brad Chmelka, have formed a company to look into nearer-term commercial opportunities arising from their research. SBA Materials, named for the airport abbreviation for Santa Barbara, was formed in 2000 to develop functional nanoporous[*] materials. Remember that biology starts the fabrication of nacre with a protein stencil of nanometer-sized pores. This is part of the inspiration behind the new company.

SBA Materials has been conducting research on potential applications of nanoporous materials and is not yet ready to say what its commercial focus is going to be. It has a variety of interesting possibilities to choose among:[†]

- Coatings with low electrical response[‡] for use in the next generation of integrated circuits ("computer chips")
- Improvements in "chromatography," the procedure for separating out and identifying proteins and other molecules important in biotechnology and pharmaceutical development
- Materials permeated with a vast network of nanoscale channels that provide a huge amount of surface area, used in industrial catalysis, such as "cracking" heavy oil to break up its large molecules into gasoline and other useful hydrocarbons
- Other applications, including biosensors, optical devices, and energy storage.

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[*] Tech talk: The scientific literature distinguishes three categories of porous materials, according to the size of the pores. *Microporous* means holes up to 2 nanometers wide, *mesoporous* indicates pores between about 2 and 50 nanometers, and materials with larger pores are called *macroporous* (see, e.g., *Microporous and Mesoporous Materials*, www.Elsevier.Nl/locate/micromeso). The materials discussed in this section fall into the mesoporous category. This report does not use this jargon, but refers to them as nanoporous because the pores are on the scale of nanometers.

[†] *The current role of mesostructures in composite materials and device fabrication* by Ryan C. Hayward, *et al.* in *Microporous and Mesoporous Materials*, v 44-45, 2002 April 6, p 619..24

[‡] Tech talk: The strength of a material's response to nearby electric charge, in terms of induced internal electric field strength, is called *permittivity* or *dielectric constant* and is represented by the Greek letter ε (in physics) or by k (in engineering). So a material in which this response is small is called a *low-k* material. This is necessary for the support structures (*substrate*) in high-density computer chips so that current can flow through the circuits without being affected by electrical response in the surrounding material.

Nano Coast Players — Biomimetics

- UCSB:
  - **Brad Chmelka**, Chemical Engineering (www.ChemEngr.UCSB.edu/~ceweb/faculty/bradc)
  - **Tim Deming**, Materials, Chemistry (www.MRL.UCSB.edu/~tdeming)
  - **Paul Hansma**, Physics (HansmaLab.Physics.UCSB.edu)
  - **Daniel Morse**, Molecular Biology (www.LifeSci.UCSB.edu/mcdb/faculty/morse)
  - **Galen Stucky**, Materials, Chemistry (www.Chem.UCSB.edu/~stuckygroup)
  - **Herbert Waite**, Molecular Biology (www.LifeSci.UCSB.edu/mcdb/labs/waite)
  - Materials Research Lab, Solution Synthesis Group (www.MRL.UCSB.edu/mrl/research/irg2.html): **Frederick F. Lange**, Group Leader
- SBA Materials (www.SBAMaterials.com): **Nick Colaneri**, CEO

Long-Range Prospect: Spintronics

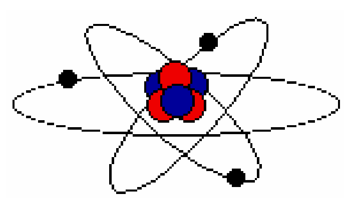
A New Dimension for Electronics

Electrons have:

The economic miracle of the 20th century was largely founded on technologies for manipulating a single subatomic particle — the electron. In particular, these technologies took advantage of two basic characteristics of the electron, first that it is light (i.e., has low mass) so it is easy to move around in certain materials, and second that it has an unchangeable quantity of something called electric charge, which makes it interact in definite and predictable ways with atoms and with other electrons.

• Low mass

• Uniform electric charge



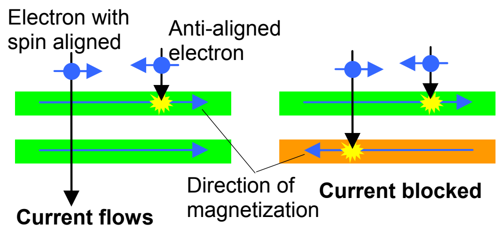
The low mass and electric charge of the electron are used in the 20th-century technologies of electricity and electronics. Spintronics adds consideration of the electron's spin.

The easy motility of electrons became the foundation of electricity, which powers light bulbs, refrigerators, and washing machines. The ability to control and keep track of electric charge is the basis of electronics, which gives us television, computers, and automatic garage door openers.

• And orientable spin

There is another characteristic of electrons that lies unutilized in all this technology. Like most other subatomic particles, electrons have spin.* And like its charge, the spin of an electron determines how it interacts with atoms and with other electrons. And again like its charge, the amount of spin an electron has is unchangeable. However, spin is more complicated than charge because it has direction, and the direction that a particular electron is spinning in can and does change.

* Tech talk: The *spin* of a subatomic particle, such as an electron, is one of the great mysteries of modern science. It means that in some ways an electron behaves like a twirling top, except that if you look closely, there is nothing there that is spinning around.



Giant magnetoresistance (GMR), the first spintronic technology, came to market in the late 1990s and is used in all hard disks sold with computers today. Layers of material are magnetized in either the same or opposite directions, making them act like a polarizing filter on spinning electrons.

$25 billion worth of spin

Less than ten years from lab to market

Spintronics is a new field of technology that takes into account the spin of electrons, along with their charge and low mass. It has already scored its first major win — in data storage. Anyone buying a computer in the late 1990s cannot have helped noticing the large spurt in hard-drive capacities. Today, it is hard to find a computer on the market with less than 20 gigabytes of storage. The reason for this huge leap from the megabyte capacities of the early 1990s is a new technology, called *GMR* (see accompanying illustration). In an astounding story of commercialization, GMR was only first discovered as a laboratory phenomenon in 1988, yet IBM was able to launch the first GMR-based hard drive only nine years later in 1997, and now all hard drives from all manufacturers (140 million per year worth $25 billion) use the technology.

If UCSB physicist David Awschalom is right, GMR is just the tip of the iceberg in exploitation of electron spin. One of the leaders in spintronics research, Awschalom identifies three stages of evolution for this field of technology according to the type of material it works in:

- **Magnetic metals.** The GMR technology described above uses ordinary magnetic metals (metallic alloys that, like iron, can be magnetized) to control the flow of electrons according to their direction of spin. Another technology in this category, magnetic random-access memory (MRAM) is due to enter commercial production in 2004. It promises high-density, high-speed, nonvolatile memory that could allow for the first "instant-on" computers (no boot-up required).

Spin transistors

- **Magnetic semiconductors.** There have been attempts in the past to invent new materials that combine the properties of both magnets and semiconductors, but success has been limited. Awschalom and others are searching for new ways to magnetize semiconductors. If this can be accomplished, the results will move beyond the memory applications of GMR and MRAM to active data processing in spin-based transistors. Transistors that operate on the basis of electron spin are anticipated to operate much faster and use much less energy than today's charge-based transistors.

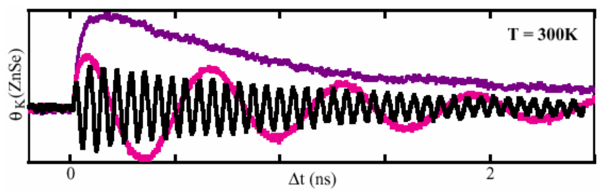
Quantum computing

- **Individual electrons.** The first two stages above work with *spin currents*, streams of electrons set up to spin in a uniform direction. However, beyond that lies the possibility of manipulating the spin directions of individual electrons in molecules. Achieving this may lead to computers that utilize their "quantum" nature, allowing for molecular devices that perform thousands of calculations simultaneously. This would not only allow certain computations to run orders of magnitude faster, but would create the possibility of performing tasks that are simply out of reach of today's computers.

While Awschalom's research group focuses primarily on stage 2, magnetic semiconductors and spin transistors, it keeps a watchful eye out for clues that will lead to the more elusive third stage of quantum computing based on individual electron spin.

Working with spin currents

Important progress is being made on stage 2. One of the central challenges is to set up spin currents in which the uniformity of spin direction is stable. This means the spin states should last long enough to be useful, which in this case means at least several nanoseconds. Several factors work against this stability: time, temperature, and the passage of a current from one material into another. Yet Awschalom and collaborating teams have developed methods to use pulsed, polarized laser light to set up a uniform spin direction in pools of electrons in two kinds of semiconductor materials, gallium arsenide (GaAs) and zinc selenide (ZnSe). Measurements have shown these spin states to persist for a few nanoseconds at room temperature and even a few hundred nanoseconds at much lower temperatures. The researchers have even found techniques that allow the spin states to persist when passing a current of spinning electrons from gallium arsenide into zinc selenide, as shown in the accompanying figure.



Decay of electron spin state for current passing from gallium arsenide into zinc selenide at room temperature. The demonstrated persistence of spin information for a few nanoseconds under such circumstances is a promising development in the drive to use spin in the operation of future electronic devices.*

What is the potential commercial value of Awschalom's work? It is far too early to tell with certainty. The semiconductor industry is up against tremendous limiting factors in its drive to continue pushing the "Moore's-law" improvements in price:performance of computer chips. If spin transistors can be made to work in a practical way and then refined for mass production, then they may have a chance at becoming the basis of a future generation of ubiquitous computer chips. Obviously, the value in that case would be enormous. When could this happen? With sufficient ongoing breakthroughs, there could be spin transistors operating in the laboratory in three to five years. Mass production for mainstream applications is likely ten to fifteen years away, or longer.

Possibly as revolutionary as transistors

However, that is only stage 2 in Awschalom's progression. If in the course of developing magnetic semiconductors, practical concepts arise for spintronic quantum computing, the result could be not just a new generation of computer chips, but a whole new generation of computation. Rather than contemplating value on the basis of advancing the performance of transistors, this may be a technology with a value comparable to that of the transistor itself. The invention of the transistor changed the world so radically that, even in retrospect, it's hard to know what kind of metrics to use to calculate its net commercial value or economic impact.

Nano Coast Players — Spintronics
UCSB: **David Awschalom**, Physics (www.iQuEST.UCSB.edu/sites/Awsch)

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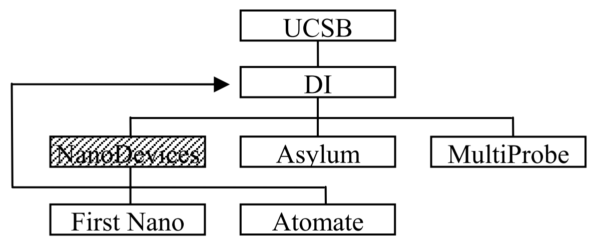
* *Spintronics: A Spin-Based Electronics Vision for the Future* by S. A. Wolf, *et. al* in *Science*, v 294, p 1493, 2001 November 16

Higher-Generation Offspring: An Industry Germinates

A successful industry is like a forest. Big trees drop seeds that sprout saplings in the vicinity. Thus Shockley Semiconductor begat Fairchild Semiconductor, which begat AMD, LSI Logic, Teledyne, Rheem, National Semiconductor, and, most importantly, Intel. This is the genealogy of Silicon Valley, home of what is arguably one of the most successful industries of all time.

Genealogy of Santa Barbara nano-tool industry

The process has started in Santa Barbara nanotechnology. Within a year after Veeco acquired Digital Instruments, which was itself started by a former UC Santa Barbara professor (see *The Probe Microscope*, page 15), two new companies were started by former DI employees, Asylum Research and NanoDevices. Another company, MultiProbe, arose in 2001. In June 2003, NanoDevices itself split in two, with one segment reacquired by Veeco and the other continuing business as First Nano. In the fallout of that event, another company was formed by former NanoDevices personnel, Atomate.



The lineage indicated here represents only the former employment of the companies' founders and does not imply any formal relationship among the companies nor any transfer of technology.

Unlike trees, industrial offspring often germinate out of discontent. If a company is less successful than some aggressive employees think it could be, or if the management culture leaves some dissatisfied, this spurs people to think of greener pastures. Problems like these at Shockley and Fairchild stimulated some staff to start their own ventures. Intel, however, with its long run of phenomenal success in a popular, horizontal management culture, has generated fairly few of its own offspring.

Imprint of Elings' personality on founding culture of DI

Talk about horizontal management, when Veeco took over DI, there was no organizational chart. Virgil Elings didn't believe in meetings and he stimulated creativity by developing theoretical arguments and challenging employees to prove him wrong. It was inevitable that a number of talented people who thrived in such an environment might be less than comfortable with the East Coast "suits" who acquired the company.

Competition versus symbiosis

There is an interesting contrast in the relationships between DI and the companies its former employees started. Asylum Research makes probe microscopes in direct competition with Digital Instruments. MultiProbe makes a different kind of probe microscope that Digital decided not to pursue (see below). However NanoDevices made a line of probes for use in probe microscopes, for which DI was its largest customer. Ultimately, this is the line of its business that was reacquired by Veeco.

Nanotubes

As an adjunct to its probe business, in 2003 NanoDevices introduced a new product line completely unrelated to microscopy. This is the part of NanoDevices that now continues to operate as First Nano. The new product is *EasyTube*, a turn-key system for making "carbon nanotubes," an important new kind of material at the center of much nanotech research (see picture on page 18). Making nanotubes, a process of accumulating individual carbon atoms into a precise 3-dimensional pattern, can be a research project all by itself. But when scientists explore new characteristics and applications of nanotubes, they want to get the tubes easily and move on to performing experiments with them. This is EasyTube's market, analogous to the market for probe microscopes when Digital Instruments launched the NanoScope 16 years ago. Furthermore, also like probe microscopes, while the EasyTube is a complex system to develop, it is relatively inexpensive to manufacture. Thus First Nano may be positioned to enjoy high margins with this product, as DI did with the NanoScope. It is no surprise that the senior member of the ex-Digital team behind NanoDevices, and now the chairman of First Nano, is Virgil Elings himself, founder of Digital Instruments.

The difference between the NanoScope and EasyTube is that there seems to naturally be a much bigger market for microscopes than for a nanotube maker. That is unless a "killer application" comes along, such as serving as a replacement for the silicon in semiconductors. In any case, with ongoing growth of nanotech research around the world, EasyTube has the potential to become a lucrative product. It just leaves one wondering what Virgil Elings might find up his sleeve next.

Nanowires

Atomate, founded by former NanoDevices personnel in 2003, produces equipment for making not only nanotubes, but also *nanowires*. These are yet another novel form of material with important potential applications in nanoscale electronics. The company also plans to offer additional tools for nanotech research in the near future.

Multi-probe microscopes

MultiProbe started up in 2001 to offer probe microscopes with several probes instead of one. This enables inspection and functional testing of nano-scale electronic circuits in ways that a single-probe microscope cannot perform.

Nano Coast Players —Nano-Relevant offspring from Digital Instruments

- Asylum Research (www.AsylumResearch.com):
  Jason Cleveland, Chairman; **Roger Proksch**, President
- Atomate (www.Atomate.com): **Brian Lim**, CEO
- First Nano (www.FirstNano.com):
  Virgil Elings, Chairman; **Dennis Adderton**, President
- MultiProbe (www.MultiProbe.com): **Andrew Erickson**, President

Other Interesting Projects

The research projects and technology companies discussed above only begin to scratch the surface of nano-related R&D going on at UCSB or elsewhere on the Central Coast. Remember that the Web site for the UCSB branch of the California NanoSystems Institute lists 59 associated faculty members, and even that is not a complete list of faculty on the campus doing research in the field. Just to allow for a somewhat broader taste of the variety of work underway, this section provides a very brief description of a few more projects and companies.

Some More Nano-Relevant Projects at UCSB

Optoelectronics

A new convergence of photonics and electronics develops technologies that manipulate the interplay between electrons and visible or near-visible light. Applications range from higher capacity fiber optic telecommunications, allowing faster transmission of data files, to room lighting with solid-state devices. This work is mostly at the micron scale, but is starting to venture into the nano realm, such as studying how crystalline imperfections affect the optical properties of gallium nitride semiconductors.

Faculty: Blumenthal, Bowers, Coldren, DenBaars, Gossard, Mishra, Nakamura, Speck

Spin-offs: Cree Lighting (formerly Nitres), Agility Communications, Calient Networks, others

Conductive plastics

It used to be that metals were conductors and plastics were insulators. Not anymore. Technology for which UCSB Prof. Alan Heeger shared a Nobel Prize in 2000 uses the carbon chain in certain polymers to conduct electricity. Applications include brighter cell phone displays and biosensors that detect the presence of infectious DNA.

Faculty: Bazan, Heeger, others in Center for Polymers and Organic Solids

Spin-offs: DuPont Displays (formerly Uniax), Sirigen

Drug delivery

The classic 1960s science fiction thriller, *Fantastic Voyage*, presaged one of the major predicted applications of nanotechnology — tiny devices that will enter the human blood stream to destroy malignant cells, remove clots, or repair damaged tissue. The first step towards that bright medical future is technologies that provide better temporal and positional control over the delivery of drugs in the body. Concepts under study at UCSB include an automated nanoliter injection device, polymer nanospheres that hitch-hike on red blood cells to avoid being flushed by the body's defense mechanisms, DNA-wrapped nanomagnets that can enter a cell and use its internal transport mechanisms, and "double-bagging" of pharmaceutical agents.

Faculty: Butler, Mitragotri, Zasadzinski

Spin-off: Advanced Encapsulation

Quantum dots

Modern electronics technology has advanced from controlling the flow of electrons within ordinary bulk materials to the ability to confine electrons to thin surfaces, narrow lines, and finally tiny dots about 10 nanometers across or smaller. Because of the quantum physics that governs behavior in such systems, they are called, respectively, quantum wells, quantum wires, and quantum dots. Interesting possibilities arise for extraordinarily high-density electronic devices, including memory, lasers, resonators, and even transistors.

Faculty: Gossard, Hu, Imamoglu, Petroff, Strouse

Nanocluster and zeolite catalysis

Most chemical processing today is carried out in vats of liquid, where catalysts are mixed into the formulation to speed up the reactions. This rather ancient methodology is plagued with problems, such as how to separate out the desired reaction products from the mix and how to recover the catalyst for reuse. Research is underway on alternative techniques that flow the reagent chemicals over a solid surface on which are dispersed a pattern of nanoscale catalytic particles.

Other work on catalysis includes using nanoporous materials (artificial *zeolites*) to drastically increase the surface area available for flowing reagents.

Faculty: Buratto, Cheetham, Lange, McFarland, Metiu, Scott

Non-UCSB Companies

Not everything nano orbits the university. A number of nanotechnology companies on the Central Coast have arisen independently of UCSB.

Nanoscale structures improve performance of automotive catalytic converters

Catalytic Solutions has developed a new way to make catalytic converters, the devices that transform noxious fumes from a car engine into benign gases. Today's converters work by passing exhaust fumes over a coating of precious metals that encourages ("catalyses") the beneficial chemical transformations. The metallic coatings (such as platinum or palladium) are expensive and over time the nanoscale particles in them coalesce into larger clumps that reduce the effectiveness of the device. Catalytic Solutions' technology uses more common (and therefore less expensive) materials in more stable nanoscale structures that maintain their effectiveness longer.

The company has been a poster child of entrepreneurial promise for the Central Coast. Still operating as a private company, investors include General Electric, JP Morgan, BASF, and Honda Motor Company.

Oxnard, California, Web: www.CatSolns.com

Improved composites through self-assembled monolayers

Interface Sciences Corporation is commercializing self-assembled monolayer (SAM) technology under development at Battelle laboratories in Richland, Washington since the mid-1980s. This technology improves component bonding in fiber composites, allowing them to be made much stronger, yet lighter, and also to better resist corrosion and degradation. The company sublicenses the technology to major industrial customers and is developing new products enabled by SAMs.

Goleta, California, Web: www.InterfaceSciences.com

Nanoscale-precision positioning device

Invenios makes a line of manufacturing tools with nanoscale precision that are used in, among other things, probe microscopes (see page 15). The company is currently building a device for Zeiss, the German optical equipment manufacturer, that will move an instrument element in increments of 20 nanometers.

Goleta, California, Web: www.Invenios.com

More efficient way to make nanocrystals

Kreido Laboratories (formerly **Holl Technologies**) is developing and licensing new technology for chemical reaction systems. Chemical companies process materials in huge vats that are stirred to encourage the atoms of one component to come into contact with atoms of other components so that chemical reactions can take place. Kreido's technology is a small reactor that moves fluids through a tiny spinning chamber that causes ultra-fast mixing of components and increases reaction rates by up to 4,500 times. Aside from simple economic advantages in conventional chemical processing, a specialized application under investigation is in the generation of nanocrystals — pure, crystalline particles of special materials as small as five nanometers in size.

In November 2003, Kreido announced closing a new round of investment from Unilever Technology Ventures.

Camarillo, California, Web: www.Kreido.com

Nanoscale-precision positioning device

MEMS Precision Technology is developing biochemical sensing devices. In conjunction with that it has developed a nanoscale-precision positioning device suitable for use in probe microscopes (see page 15).

Santa Barbara, California, Contact: BLNorling@AOL.com

Challenges and Opportunities

This third and concluding part of the *Nano Coast* report looks at several issues relevant to exploitation of nanotechnology on the California Central Coast, and more specifically in the region around Santa Barbara. The first section reviews some of the planned course of near-term action at the UCSB branch of the California NanoSystems Institute. Next is a look at UCSB's track record in fostering commercial applications for technologies developed in its labs – and what can be done to improve on it. The third section discusses how geography and politics affect the exploitation of business opportunities in this area.

Part III:
- *CNSI*
- *UCSB Tech Transfer*
- *Regional Issues*

Ramp-Up of CNSI at UCSB

The California NanoSystems Institute is on track to be one of the most important centers of nano-focused research. A world-class faculty, a healthy level of financial backing, and a powerful board of business advisors combine to create the opportunity to not only make important discoveries, but to then find productive homes for them in the form of commercial products.

Administrative and operational issues

Certain aspects of the administration of the institute are still under consideration, such as the right to autonomously define new faculty positions, the form of interaction and collaboration with industrial partners, and the type of educational outreach to be offered to the community. Another important issue is technology transfer, which is the subject of the next section. The caliber of membership on the Business Advisory Board will help to ease tech transfer, but it cannot make tech transfer happen without adequate and appropriate support from the universities.

Broadening the scope of research

While the proposal to establish CNSI built on a strong foundation of ongoing nanotechnology research at UCLA and UCSB, there are certain areas where academic coverage is planned to be enhanced with new faculty positions. Examples include

- Bioengineering (in conjunction with the new Institute for Collaborative Biotechnologies, which has significant ties to CNSI)
- Instrumentation for nano-scale experimentation
- Nanoelectronics
- Simulation and modeling of systems spanning multiple length scales
- Nanosystems architectures (An architecture can be thought of as a set of rules that define the relationships and interactions of elements of a system. The functioning of a modern computer can be described in terms of its architecture of CPU, memory, and input/output. New concepts, such as quantum computation (see page 22), will require entirely new sets of rules.)
- Bioinformatics (the computational analysis of biological systems, such as in the Human Genome Project)
- Interface of scientific analysis and graphic arts (CNSI already has visionary participation from UCSB music professor JoAnn Kuchera-Morin, whose radical concepts for the new building's auditorium could make a scientific lecture feel more like an IMAX movie.)
- Interface of nanotechnology and society (There is a proposed collaboration with UCSB political science professor Bruce Bimber on considering how potential benefits and threats of the technology could affect human health, the environment, economics, war, and even theology, and what to do about it.)

Nanotech conference

A conference hosted by CNSI at UCLA in December 2003 was a one-day event featuring a roster of nanotech luminaries. This is a good start, but an institute of the caliber of CNSI deserves more. There are today many major conferences on nanotechnology taking place in diverse corners of the world, yet few have the intellectual muscle behind them of a CNSI. As part of its outreach program, CNSI might consider partnering with a major event producer to put on a week-long event with overlapping technical and business tracks. An associated trade show could feature not only existing companies with products, but also new laboratory research open for commercial exploitation.

Tech Transfer at UCSB

Technology transfer is the process of developing commercial applications for the results of research carried out at a university, government lab, or large industrial company. It is a fairly recent concept, which largely came about in the 1990s as organizations performing basic research came under increasing pressure to generate financial justification of their work. Tech transfer usually takes the form of a royalty-bearing license on a patented invention. In most cases the licensee is a mid-size to large company with a sufficient development budget to exploit the invention and with established manufacturing and marketing operations. However, in appropriate circumstances the licensee can be a new start-up established specifically for the purpose of commercializing the invention. In this case, the licensor organization may take a small equity position in the new company in partial lieu of royalties.

While tech transfer can generate substantial revenues to the inventing organization, it can also serve as an economic engine, stimulating the launch of new products in the marketplace as well as entirely new businesses.

Two distinct aspects of technology transfer process

The lifeblood of technology transfer is intellectual property (IP), usually in the form of patents. The tech transfer process performs two critical and utterly different roles with this property:

- **Management of the IP**, which includes assessing inventions for patent-worthiness, prosecuting patent applications, and defending the patent portfolio
- **Marketing**, which involves identifying prospective licensees, promoting the IP to them, negotiating licenses, and then monitoring them. Where existing prospects are limited, it can involve coaching interested student or faculty entrepreneurs to start a new business and making introductions to sources of seed funding and start-up management

Given the complexity and variety of projects in any major research organization, together with the arcane language of patents and the difficulty of predicting markets for new technology, setting up a tech transfer operation is a major undertaking.

Small schools do far less tech transfer

Most major research universities have embraced technology transfer and have established significant offices devoted to the process. Within the UC System, the six campuses with the largest numbers of technical (science, engineering, and medicine) faculty have built significant tech transfer offices and generate substantial licensing revenues. The three smaller schools, Riverside, Santa Barbara, and Santa Cruz, have much smaller tech transfer staffs and generate much smaller revenue. These and other relevant data are shown in the following table.

Selected Tech Transfer Data for the University of California System, FY2001									
	Berkeley	**Davis**	**Irvine**	**Los Angeles**	**Riverside**	**Santa Barbara**	**Santa Cruz**	**San Diego**	**San Francisco**
Technical faculty	599	710	480	806	199	262	178	527	355
Tech transfer staff	8	11	8	14	2	0.5	0.5	29	7
Inventions reported in year	106	86	87	129	30	81	15	265	167
Invention portfolio	667	612	347	686	184	290	76	1,038	1,104
Active US patents	371	274	128	320	66	141	15	370	576
Total active licenses	167	410	36	94	111	19	1	171	239
Adjusted gross income, $M	5.4	9.6	5.6	8.4	1.0	0.7	0.0	5.4	29.2
Net income, $M	1.9	2.7	3.2	1.9	0.0	(0.4)	(0.2)	(1.9)	1.5

Source: Faculty numbers: Fact sheets linked at www.UniversityOfCalifornia.edu/campuses/welcome.html
Other data: *UC Technology Transfer—Annual Report 2001* (www.UCOP.edu/ott/ars/ann01/ar01.pdf)

UCSB should be an exception

The statistics in this table indicate the need for a change. UCSB's technical faculty, while one of the smallest and least funded in the UC System (see *Not a wealthy school*, page 6), is disproportionately productive of intellectual property. It has 141 active US patents, or 54 patents per 100 technical faculty members, which is better than most of the other campuses. Yet since managing the filing of patents is one of the responsibilities of tech transfer, this number is probably depressed from what it could be, given adequate staffing for this purpose. On the other hand, one can be more certain that the lack of staff to concentrate on marketing this IP is a great part of the reason for the very low number of active licenses, and correspondingly, the small royalty stream.

A real tech transfer office at UCSB is needed — and justified — now

With the establishment of CNSI and ICB, not only will there be more science and engineering faculty at UCSB, but the very reason for the creation of the new institutes was to increase the flow of creative ideas in the university, and this should mean an even greater amount of IP. UCSB, CNSI, and ICB need to not wait for some threshold of faculty size or portfolio size to justify building a real tech transfer office. They need build it now.

Regional Issues

If the licensee of a university technology is a new start-up, then it usually makes sense for the company to locate near the campus. Often faculty and/or student inventors will hold part-time positions in the new company and ongoing research in university labs may be of interest to the company as well. At UCSB, even if there is no need for an ongoing connection with the university, the founders are likely to choose to remain in the Santa Barbara area – simply because it is such a desirable place to live.

And therein lies a major source of consternation for the region – the opposing forces of economic growth and quality of life.

The idyllic environment of the narrow coastal plain where Carpinteria, Santa Barbara, and Goleta is beginning to choke in traffic and other symptoms of crowding. As the housing supply dwindles, the price of residential real estate has been skyrocketing. Santa Barbara appears to be at a crossroads and a number of community and political groups are working and fighting to promote a positive future from the region.

Watersheds and Topography of the Conception Coast Region, California
Conception Coast Project (www.ConceptionCoast.org)

The regional context of Santa Barbara. The yellow oval encircles the cities of Goleta, Santa Barbara, and Carpinteria, as well as UCSB. Across the Santa Ynez Mountains and to the northwest lie the North County cities of Solvang, Lompoc, and Santa Maria. To the southeast is Ventura County, with the broad plain containing Ventura, Oxnard, Thousand Oaks, and Simi Valley.

Santa Barbara may be anti-growth, but it is not anti-business

The community of Santa Barbara/Carpinteria/Goleta has long had a strong sentiment against urbanization, i.e. population growth. Often this has been interpreted as anti-business. However, the business climate is not really worse than other places in Southern California. The primary (and increasing) difficulty for businesses is for employees to be able to afford housing without commuting unreasonable distances. The following table presents the most recent US census data for both people and businesses for three metropolitan satellites of large cities. Data for the US, California, and Los Angeles are also included for comparison. This information shows that, while Santa Barbara County has a much smaller population than the other satellite metros, it has disproportionately more manufacturing, both in terms of business locations and jobs. The county has 1.3 manufacturing establishments per thousand population with 37 manufacturing employees per thousand, versus 1 establishment and 34 employees for Riverside and compared to 0.8 and 26 for Sacramento.

Economic Demographics of Selected California Regions

Region	Land Area	Population			Manufacturing								
		All	Density	Urban	Est'ts	Revenue	Payroll	Employees	Emp. / Est't	Est'ts / Pop'n	Rev. / Emp.	Av. Pay	Emp / Pop'n
	k mi^2	M	mi^{-2}	M	k	\$M	\$M	k		k^{-1}	\$k	\$k	k^{-1}
United States	3,536.3	281.4	79.6	222.4	363.8	3,842.1	572.1	16,888.0	46.4	1.3	227.5	33.9	60.0
California	156.0	33.9	217.2	32.0	49.4	379.6	65.8	1,809.7	36.6	1.5	209.8	36.3	53.4
Los Angeles County	4.1	9.5	2,344.7	9.5	17.9	106.7	20.3	622.3	34.7	1.9	171.5	32.6	65.4
Riverside/San Bern. Metro	27.3	3.3	119.4	3.1	3.4	19.4	3.2	109.6	32.1	1.0	176.6	28.8	33.7
Sacramento/Yolo Metro	5.1	1.8	352.7	1.6	1.5	14.6	1.7	47.7	32.0	0.8	305.1	35.4	26.5
Santa Barbara County	2.7	0.4	145.8	0.4	0.5	2.8	0.6	15.0	29.9	1.3	184.9	39.0	37.5

"Est't" = "Establishment"
"k" = "thousand"
"M" = "million"

Sources: Land area: *State and Metropolitan Area Data Book: 1997-98* (www.census.gov/prod/3/98pubs/smadb-97.pdf)
Population: *Census 2000 Summary File 1 (SF 1) 100-Percent Data — Detailed Tables* (http://factfinder.census.gov)
Business: *1997 Economic Census — Summary Statistics* (www.census.gov/epcd/ec97/us/US000.HTM)

This data suggests that the Santa Barbara area has a reasonably strong manufacturing base given its population. It's the unwillingness of the community to accommodate increasing population that creates a problem for proponents of increased business activity.

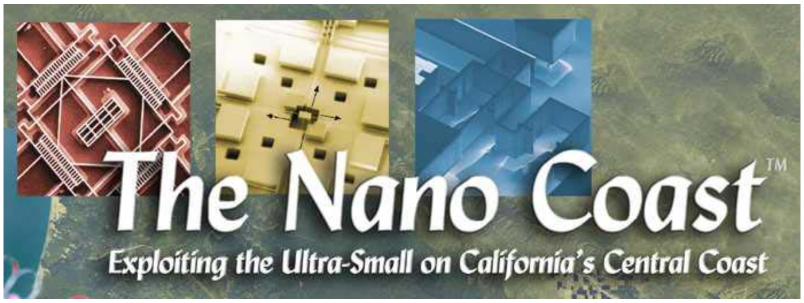
Area can accommodate small start-ups

This is not a problem for the freshly minted start-up with a handful of new PhDs working the bugs out of a new technology. A company that size can readily find commercial space to rent, and the recently graduated students are likely not yet highly demanding in their choice of housing. But two problems arise as the company grows. First, when it is time to recruit a marketing manager or other mid-level executive with specific industry experience not available in the local market, the candidates for that position are likely to be shocked by the cost of trading homes from their current locations. And second, when the company grows up to a hundred employees and beyond, it also becomes difficult at that point to find or build contiguous office space for all of them.

Some UCSB spin-off companies have found a solution to both problems in moving a short distance out of town, either to Ventura County or, less frequently to northern Santa Barbara County. However, there are also going to be limits to how many companies can do this. These neighboring regions have also been developing environmental activism that seeks to limit their population growth as well. This sentiment in these areas is not yet as vehement nor as experienced as it is in Santa Barbara/Carpinteria/Goleta, but it seems to be gaining support. The residents of these communities are increasingly deciding that they also do not want to become an extension of the Los Angeles megalopolis.

Brain trust for an industry

What does this mean for the Nano Coast? It establishes the character with which the region can participate in the nanotechnology revolution. Clearly, the Santa Barbara/Carpinteria/Goleta area will not be a place where brilliant little nanotech companies get big and build glass and steel headquarters buildings with acres of parking. Rather, the role for Santa Barbara is that of the elegant brain trust, an intellectual powerhouse for the up-and-coming industry, where brilliant ideas are incubated and transplanted for major growth elsewhere.



Appendices

Nano-Relevant UCSB Departments and Research Units

UCSB Projects Listed in the California NanoSystems Institute Proposal

Vital Statistics of Universities in the UC System
and Some Major Research Universities

Acknowledgements

Nano-Relevant UCSB Departments and Research Units

Department / Research Unit	Start [3]	$k / year	Leader
Academic departments and **campus centers and projects** [1a]			
College of Engineering [2c]			Matt Tirrell
Department of Chemical Engineering			David Pine
Department of Electrical and Computer Engineering			Umesh Mishra
Compound Semiconductor Research Laboratories (CO-SEARCH)	1990		Mark Rodwell
Center for Non-Stoichiometric Semiconductors (PRET)	1995		Umesh Mishra
Multidisciplinary Optical Switching Technology Center (MOST)	1996		John Bowers
Walsin Lihwa Center for Electronics and Photonics	2001	2,000 [5]	John Bowers
Center for Advanced Nitride Elecronics [3]	2002	1,220 [4, p 13]	Umesh Mishra
Department of Materials			Fred Lange
High Performance Composites Center	1987		Francis Zok
Interdisciplinary Center for Wide Band-Gap Semiconductors	1998		James Speck
Solid State Lighting and Display Center	2000	500 [6]	Shuji Nakamura
Center for Multifunctional Materials and Structures [3]	2002		Anthony G. Evans
Materials Research Lab (MRL)	1992	5,000 [see pg 10]	Anthony Cheetham
Mitsubishi Chemical Center for Advanced Materials (MC-CAM)	2001	2,500 [6]	Glenn Fredrickson
Associate Dean of Bioengineering			Alison Butler
College of Letters and Sciences			
Division of Mathematical, Life, and Physical Sciences [2d]			Martin Moskovits
Bio-Molecular Science and Engineering			Daniel Morse
Department of Chemistry and Biochemistry			Stanley Parsons
Center for Polymers and Organic Solids	2000		Guillermo Bazan
Department of Molecular, Cellular, and Developmental Biology			Charles Samuel
Department of Physics			S. James Allen
National centers offer specialized research opportunities and a multidisciplinary environment for study at the undergraduate, graduate, and postdoctoral levels. These campus units were designated National Centers by the sponsoring federal agency or department. [1b]			
Under executive vice chancellor [2a]			
Kavli Institute for Theoretical Physics (KITP) (NSF)	1979	3,460 [4, p 6]	David Gross
Under vice chancellor for research			
Center for Biologically Inspired Nanocomposite Materials (BiMAT) (NASA) [3]	2002		Daniel Morse
Institute for Collaborative Biotechnologies	2003	8,500	Daniel Morse
Under College of Engineering			
Materials Research Laboratory (MRL) (NSF)	(see under College of Engineering)		
Under Department of Electrical and Computer Engineering			
Nanotech, a part of National Nanofabrication Users Network (NNUN) (NSF)	1994		Mark Rodwell
Optoelectronics Technology Center (OTC) (DARPA)	1990		Larry Coldren
Organized research units (ORUs) provide unusual opportunities for students and faculty to do basic and applied research in a variety of disciplines [and] operate outside of the established academic teaching departments at UCSB [1c]. Managed by vice chancellor for research [2b].			
Institute for Quantum Engineering, Science and Technology (iQUEST)	1969		Mark Sherwin
Center for Terahertz Science and Technology	1987		Mark Sherwin
Center for Spintronics and Quantum Computation	1999	1,500 [4, p 20]	David Awschalom
Marine Science Institute (MSI)	1969		
Marine Biotechnology Center	1987		Daniel Morse
Multicampus centers [1d]			
Under executive vice chancellor [2a]			
California NanoSystems Institute (CNSI)	2000	25,000 [7]	Evelyn Hu

Sources:
1a: www.ucsb.edu/academics/centers, 1b: academics/natl-centers, 1c: academics/oru, 1d: academics/multicampus
2a: http://bap.ucsb.edu/IR/orgcharts/charts0203/evc.pdf, 2b: charts0203/vcresearch.pdf, 2c: charts0203/engr.pdf, 2d: charts0203/mlps.pdf
3: http://omni.ucsb.edu/connect/resunit/research_units.pdf, 3a: That Web page says that Walsin Lihwa Center director is John Bowers.
4: Office of Research Annual Report, FY 2000-2001, http://omni.ucsb.edu/publish/orannrept02.pdf
5: http://www.engineering.ucsb.edu/Announce/walsin.html, 2001 April 20
6: http://www.engineering.ucsb.edu/Announce/mitsubishi.html, 2001 February 18
7: $100M * 3 / 3 ($100M state funds, 2:1 matching, split with UCLA) / 4 years

UCSB Projects Listed in the California NanoSystems Institute Proposal

Topic (# UCSB Faculty)	Projects with UCSB Faculty	UCSB Faculty	Partners
Nanostructures (Building Blocks (11))			
Bio-inspired nanostructures	Inorganic biomimetic synthesis ("silicon biotechnology") Q-dot arrays, optical waveguides, optoelectronic biosensors Organically templated inorganic nanostructures	Morse, Chmelka, Stucky Morse, Chmelka, Stucky, Awschalom, Petroff Chmelka, Stucky	
Inorganic quantum dots	Theory of nanocrystal growth and nucleation Surface-nucleated inorganic quantum dots Quantum dots in GaN-based semiconductors Using GaN q-dots to make ferromagnetic semiconductors Using semiconductor q-dots in magneto-electronics Using semiconductor q-dots in optoelectronics Using semiconductor q-dots in quantum computation	Metiu Gossard, Petroff DenBaars, Petroff, Speck Awschalom Awschalom, Cleland Buratto, Coldren Hu, Imamoglu	
Hybrid organic/inorganic nanostrctures	Peptide/semiconductor binding	Hu	
Magnetic semiconductors	Digital superlattices of fractional semiconductor monolayers	Awschalom, Gossard	
Molecular mechanical systems			
Other nanostructures	Quantum wires Quantum wells Organic macromolecules	Gossard DenBaars, Gossard, Nakamura, Speck Bazan	
Nanosystems for Molecular Medicine (0)			
Structural biology, informatics, and computational biology	Statistical analysis of single-nucleotide polymorphisms Protein-like structures via synthetic lipidation	Li Tirrell	
Biological nano-electro-mechanical machines (Bio-NEMS)	Bio-MEMS Controlled chemical, electrical, and optical stimulation of cells	MacDonald, Turner Coldren	
Molecular probes of cellular functions			
Differential screening in vivo in mice			
The patient			
Nanosystems for Information Technology (11)			
Memory	Near-term: 3-D optical data storage device Farther-term: Magnetic semiconductors Far: 2-D q-dot superstructures for 1-electron optical storage Very far: Spin-based data storage Spintronics (Using spin coherence for storage, computation)	Nakamura, DenBaars Awschalom, Gossard, Hu, Morse Petroff Hu, Imamoglu Awschalom	Agilent IBM IBM, Motorola
Logic	Polar and piezoelectric (instead of doped) logic devices Strong coupling of qubits with modes of a microresonator Algorithm and architecture development, systems modeling	Mishra, York Imamoglu, Hu Agrawal, Schauser, Almeroth	 HP, IBM, LANL, LLNL
Data transmission	Nanoscale optical devices Frequency filtering by photonic bandgaps due to nanostructure Chemical synthesis of photonic band gap materials Mesoporous materials for multifunction devices	Coldren, Blumenthal, Bowers Imamoglu, Hu Pine Stucky, Chmelka	Agilent DuPont
System interfaces	Digital multimedia	Kuchera-Morin	
Infrastructure (Analytics & Imaging (4) / Modeling, Simulation & Data Mining (7))			
Imaging and spectroscopy	High-resolution NMR Optical imaging Scanning probe imaging	Chmelka Awschalom Cleland, MacDonald	
Computation: Image analysis and data mining	Data visualization	Kuchera-Morin	
Computation: Simulation and modeling	Design of microfluidic bio-NEMS	Petzold	
Computation: Algorithms and architecture			
Fabrication			

Statistics: From *Research Plan* section of proposal (p 6..18): 4 main research areas, 20 subtopics, 37 projects that list associated UCSB faculty, 30 UCSB faculty and 7 partners listed for those projects. Color coding and numbers in *Topic* column refer to the five categories in the *CNSI Affiliated Faculty* section (p 32..40), which lists those 30 faculty plus Cheetham, Kramer, and Mitragotri. The CNSI Web site directory (as of Feb 12, 2003) lists 59 faculty, including those 33 plus 26 others (Allen, Aydil, Balents, Bouwmeester, Brown, Butler, Clarke, Daugherty, Frederickson, Fygenson, Gwinn, Heeger, Israelachvili, Kroemer, Long, McFarland, McMeeking, Meinhart, Moskovits, Plaxco, Pynn, Shea, Sherwin, Strouse, Sugar, and Zasadzinski).

Vital Statistics of Universities in the UC System and Some Major Research Universities

		UC System	Berkeley	Davis	Irvine	Los Angeles	Riverside	Santa Barbara	Santa Cruz	San Diego	San Francisco	dis-crep		MIT	Caltech	Stanford	UT Austin
Date established			1873	1905	1965	1919	1907	1944	1965	1912	1873			1865	1891	1891	1883
Land area	acre		1,290	3,697	1,400	419	1,160	990	3,008	2,040	135			154		8,180	350
Buildings	Masf		8.6	8.0	4.9	11.4	2.8	3.4	2.8	7.3	3.6					12.6	8.3
Library collection	M		9.0	3.0	2.1	7.3	2.0	2.6	1.3	2.6	0.7			5.0		8.0	8.0
Students																	
Undergrad	k	147.7	23.2	21.3	17.9	25.3	12.8	17.7	12.0	17.5	0.0	ok		4.2	1.0	6.7	38.6
Science and engineering	k	23.6	7.6	10.4	5.7	6.3	3.3	2.7	2.8	6.8	0.0			3.6			13.6
Grad	k	31.4	8.2	3.9	2.9	8.2	1.5	2.6	1.1	2.7	3.5	(3.4)		6.1	1.2	7.6	12.0
Science, eng'g, medical	k	19.8	3.2	2.5	1.0	2.8	0.6	1.0	0.6	1.8	3.5			3.8			3.2
Alumni	k	1,272.9	407.7	143.7	71.0	308.4	48.4	127.6	52.4	85.6	28.1	ok		92.1	20.1	166.7	350.0
Faculty																	
Regular rank		7,599	1,222	1,076	813	1,680	453	709	424	864	355	3		956	275	1,233	2,162
Science, eng'g, medical		4,103	599	710	480	806	199	262	178	527	355						716
Nat. Acad. Sciences		301	123	18	16	28	5	20	9	60	21	1			67	128	
Nat. Acad. Engineering		120	72	4	2	12	0	15	0	11	0	4			31	83	
National Medal of Science		13	6	0	1	1	0	1	0	4	1	(1)				21	
Nobel Prize		26	8	0	1	3	0	4	0	6	3	1		11		17	
MacArthur Fellowship		24	14	8	0	3	0	1	1	3	0	(6)				23	
Financial																	
Budget, total	$M		1,120.0	1,460.0	800.0	2,400.0	260.0	410.0	270.0	1,240.0	1,600.0			1,664.7		2,100.0	516.4
Expenditures research	$M	2,212.0	333.4	296.5	133.2	441.1	69.4	91.9	4.5	411.3	385.7	45.0		699.7			39.7
per tech faculty	$k	539.1	556.6	417.5	277.7	547.0	348.2	350.3	25.3	780.4	1,086.5						55.5
Expenditures, total	$M	11,062.5	1,315.4	1,723.0	961.4	1,883.4	341.5	472.7	340.9	1,493.3	1,655.9	875.0		1,535.9			516.4
Budget, capital projects	$M	5,143.4	406.7	656.1	339.6	1,595.0	230.0	247.0	250.6	715.8	470.1	232.5				266.0	
Endowment	$M	6,207.2	1,953.4	429.6	126.3	1,390.4	70.2	87.2	76.4	274.1	873.2	926.4		5,359.4		7,600.0	
Business																	
B-School			Haas	GSM	GSM	Anderson	Anderson							Sloan		GSB	McCombs
Incubation				Connect			RRTP	CEEM	MBEST	Connect				Entrepreneurship Center			ATI
Technology																	
Inventions reported, year		957	106	86	87	129	30	81	15	265	167	(9)		423			
Invention portfolio		4,982	667	612	347	686	184	290	76	1,038	1,104	(22)					
Active US patents		2,267	371	274	128	320	66	141	15	370	576	6					
Total active licenses		1,242	167	410	36	94	111	19	1	171	239			> 600			
Adjusted gross income	$M	66.7	5.4	9.6	5.6	8.4	1.0	0.7	0.0	5.4	29.2	1.3		34.5			
Net income	$M	5.2	1.9	2.7	3.2	1.9	0.0	(0.4)	(0.2)	(1.9)	1.5	(3.5)					
Tech transfer staff			8	11	8	14	2	0.5	0.5	29	7			31	9	29	8

Sources:

UC System: Fact sheets linked at www.UniversityOfCalifornia.edu/campuses/welcome.html and *UC Technology Transfer—Annual Report 2001* (www.UCOP.edu/ott/ars/ann01/ar01.pdf)
MIT: http://web.MIT.edu/facts, http://web.mit.edu/newsoffice/nr/nobels.html, http://web.mit.edu/tlo/www/qfa.html, http://web.mit.edu/tlo/www/qfa.html.
Caltech: www.Caltech.edu/at-a-glance, http://archives.caltech.edu, Stanford: *Stanford Facts — 2003* (www.stanford.edu/home/stanford/facts/Stanford_Facts_2003.pdf)
Texas: www.utexas.edu/admin/opa/facts/facts.html, www.utexas.edu/welcome/profile.html, www.utexas.edu/academic/oir/statistical_handbook/01-02

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Dean of Engineering

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Director of CNSI

Prof. Evelyn Hu, scientific director of the California NanoSystems Institute, provided valuable insights into the motivation, structure, and operation of that gestating organization, as well as the underlying realities of nanoscience and nanotechnology research.

CEO of NanoX-change.com

Brent Cappello, CEO of NanoXchange.com, a media services company focused on nanotechnology, engaged in helpful discussions about the nanotech industry as it is today and where it is headed in the future.

UCSB faculty and staff

Many other UCSB researchers and staff were generous with their time in explaining, and even demonstrating, their work.

Peter Allen	Eng'g Publications	Sherylle Englander	Office of Research	Prof. Mark Rodwell	Electrical Eng'g
Prof. D Awscholom	Physics	Ryan Epstein	Physics	Prof. Ram Seshadri	Materials
Prof. Gui Bazan	Chemistry	Prof. G Frederickson	Chemical Eng'g	Vladimir Shapovalov	Chemistry
Prof. John Bowers	Electrical Eng'g	Greg Hajic	Map & Imagery Lab	Prof. James Speck	Materials
Prof. Allison Butler	Chemistry	Prof. Alan Heeger	Physics	Brian Thibeault	NanoFab Lab
Prof. Tony Cheetham	Chemistry / MRL	Prof. Eric McFarland	Chemical Eng'g	Bill Watkins	Economic Forecast
Prof. Brad Chmelka	Chemical Eng'g	Prof. Samir Mitragotri	Chemical Eng'g	Denis Whelan	Budget and Planning
Prof. Larry Coldren	Electrical Eng'g	Prof. Daniel Morse	Molecular Biology	Holly Woo	CNSI
Joe Doyle	Materials Res. Lab	Prof. Stanley Parsons	Chemistry	Prof. J. Zasadzinski	Chemical Eng'g

Business community

A number of local business people provided insights in discussing their perspectives of nanotechnology and the local business climate.

Steve Anderson	DuPont Displays	Dave Cremin	DFJ Frontier	Joe Nida	Sheppard Mullin
Ken Babcock	Veeco-DI	Rick Davis		Mark Palmer	InRoads Technology
Chuck Bischoff	Agile Materials	Bob Dolan	CallWave.com	Spencer Pearson	
Susan Block	Block, Bowman & Assoc.	Virgil Elings		William Peitzke	Whitney Resource
Derrick Boston	CNSI – UCLA	Andrew Erickson	MultiProbe	Craig Prater	Veeco-DI
Cynthia Brock	Goleta City Council	Peter Grubstein	NGen Partners	Christy Ross	
Denis Cagan		Greg Helms	Conception Coast Project	John Schultz	UCLA Development
Jeff Carmody	Agility Capital	Richard Holl	Holl Technologies	Jason Spievak	CallWave.com
Rick Casler	Invenios	Bob Johnson	Founders Capital	Timothy Stultz	
Jon Clark	McCaw Foundation, Economic Community Proj.	Bud Laurent	Community Environ'l	Clark Taylor	Veeco-DI
		Phil Lichtenberger	Holl Technologies		
Nick Colineri	SBA Materials	Brian Lim	NanoDevices, Atomate		

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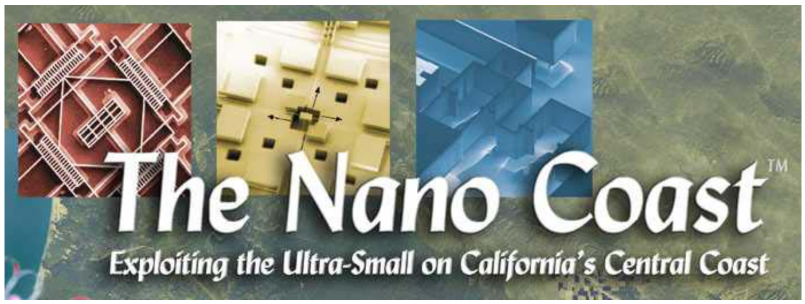
Any errors or inaccuracies in this report remain the sole responsibility of the author.



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