FOCUS ON: MRL

The Leading Edge of Collaboration

NSF renews funding for 30-year-old UCSB Materials Research Laboratory

Thirty years ago, the Materials Research Science and Engineering Center (MRSEC) — aka the Materials Research Laboratory (MRL) — in the UC Santa Barbara College of Engineering received its first funding grant from the National Science Foundation (NSF). This fall, the MRL reached a significant milestone by securing a seventh consecutive round of funding — $18 million for six years — making it one of the oldest continuously funded MRSECs.

The genealogy of the nation's twenty current MRSECs began in 1960, in the wake of the former Soviet Union's launch of the Sputnik 1 satellite in 1957, inaugurating the space race. The Advanced Research Programs Agency (ARPA), within the U.S. Department of Defense, announced the creation of three new "Interdisciplinary Laboratories" (IRLs) — at Cornell University, the University of Pennsylvania, and Northwestern University. Funding was provided to "establish an interdisciplinary materials research program and…furnish the necessary personnel and facilities" to do so. Prior to that, government-funded materials-research grants had gone almost exclusively to individual principal investigators (PIs).

The IRL program was moved to the NSF in 1972. The following year, eight more labs were established and renamed Materials Research Laboratories (MRLs). Workforce development became part of the mission, and from then on, the proposals from MRL candidates were to be judged according to updated criteria that included an institution's ability "to foster coherent, multidisciplinary and multi-investigator projects requiring the expertise of two or more materials-related disciplines." These so-called "Thrust" groups, now called Interdisciplinary Research Groups (IRGs), have transformed materials research and graduate education.

The NSF's MRL competition of 1992 led to the start of just one new center: the MRL at UC Santa Barbara, which began operation in 1993, the year all MRLs were renamed Materials Research Science and Engineering Centers. Another change that year was that, going forward, all MRLs/MRSECs would be required to engage in an open national competition to win a successive round of funding. An institution's research would thus have to remain on the very leading edge.

The late materials professor **Anthony Evans** led the initial UCSB proposal submission, and emeritus materials professor **(Sir) Anthony Cheetham** served as director of the new center through 2005. In 1997, the MRSEC moved into a new dedicated building — the Materials Research Laboratory (MRL), which is the physical headquarters for the MRSEC but also houses instrumentation and facilities, as well as faculty whose work is not directly associated with it. Cheetham was followed as director by materials and chemistry professor **Craig Hawker,** who served through 2016, and then by current director and distinguished professor of materials and chemistry, **Ram Seshadri.**

Cheetham recalls there being "great excitement when we won the competition for a new NSF-funded Materials Research Laboratory in 1992," to become the tenth MRL in the nation.

> "As a result, our facilities became the envy of many top campuses around the nation, while enhancing not only the quality of the MRL's own research, but also that in other areas of science and engineering."

"At the time," he remembers, "UCSB's shared facilities for materials research were very modest, aside from in the area of electron microscopy, so I persuaded my colleagues that we should plan a substantial multi-year investment in new instrumentation for X-rays, NMR [nuclear magnetic resonance] spectroscopy, computing, and so on. This consumed more than one-third of our total initial budget, and we continued to spend at that level for at least a decade. As a result, our facilities became the envy of many top campuses around the nation, while enhancing not only the quality of the MRL's own research, but also that in other areas of science and engineering, since everyone on campus could purchase access to the facilities."

The early years of the MRL saw many impressive successes, including from the Thrust on Conducting Polymers, which culminated in **Alan Heeger**'s being awarded the 2000 Nobel Prize in chemistry. That and numerous other pioneering outputs, together with successes both within and outside the MRL, Cheetham says, "led to UCSB's being ranked number one in the nation in materials science by *ScienceWatch* for the periods 1993-'97 and 1998-2002." The Materials Department has remained in the top five ever since.

Director lineage (from left): Sir Anthony Cheetham became the first MRSEC director in 1993, followed by Craig Hawker and current director, Ram Seshadri.

Interdisciplinary Research Groups

While shared instrumentation and facilities make UCSB an especially good fit as a MRSEC host institution, IRGs generate a somewhat similar benefit in terms of maximizing the contributions of individual faculty members. The 21 previous IRGs at UCSB have led to dozens of groundbreaking findings achieved through novel approaches in wide-ranging fields of inquiry linking the MRL to departments across campus.

Under the umbrella of biomimetics came long-term studies on the biomineralization processes that marine creatures use to strengthen their shells and even their jaws, as well as the chemistry and mechanics of how mussels create the waterproof glue they use to adhere to rocks in turbulent tidal zones. MRSEC IRGs have led to groundbreaking work on templating block co-polymers and block co-polymer lithography, and to equally impressive results in numerous other materials fields.

Multiple start-ups have been generated out of IRGs. Uniax, founded by Heeger and UCSB alumnus **Paul Smith,** was purchased by DuPont in 2000, and professors of electrical and computer engineering **Umesh Mishra** (now COE dean) and **Steven DenBaars** used a MRSEC seed grant to pursue some of the first gallium nitride (GaN) research on campus. They founded Nitres in 1996, which in 2000 was sold to LED manufacturer Cree (now Wolfspeed). GaN is, of course, what UCSB materials professor **Shuji Nakamura** previously used to develop the blue LED, for which he won the 2014 Nobel Prize.

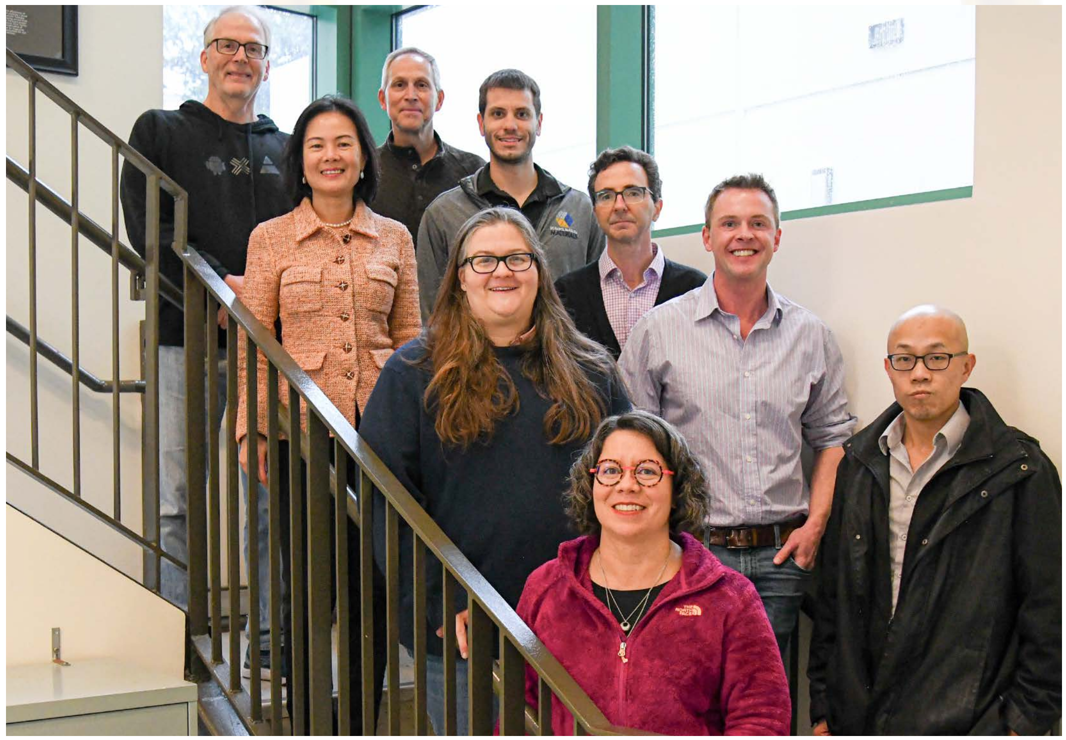
Apeel, the hugely successful company that developed and sells an all-natural plant-based coating to extend the shelf life of fresh produce, also has roots in the MRL/MRSEC, with founder **James Rogers** having earned his PhD in materials at UCSB.

Motivated by fundamental chemistry research performed in an IRG, Craig Hawker developed a general synthetic toolbox based on Click Chemistry. Then, inspired by those foundational studies, he and his former PhD student **Eric Pressly** created the active ingredients that became the patented basis for Olaplex, a product — and a successful company — that has changed the hair-care industry. Hawker recalls developing the science for the company in Pressly's garage lab and working alongside the founders of Apeel as "a magical time."

The latest round of MRSEC funding supports two IRGs, which include nine faculty who are new to the MRSEC. IRG-1 — Electrostatically Mediated Polymer Processing — is focused on exploiting the charge inherent in ions to create unique materials, while IRG-2, titled Bioinspired Plasticity, is aimed at expanding the theoretical and experimental knowledge of soft materials called hydrogels.

"It's not about what we're doing individually as researchers," says **Christopher Bates,** an associate professor of materials, associate director of the MRL, and co-PI on IRG-1. "It's about what we can do as a community of researchers tackling problems together in ways that we wouldn't normally think about individually."

"The biggest advantage of the MRL is its ability to bring people together," adds **Rachel Segalman,** a professor of chemical engineering and materials on IRG-1. "Nobody involved with the MRSEC is in it for any other incentive than that they want to be in the same room with experts in their fields who are generating novel and exciting ideas as a team. The MRSEC provides that intellectual space."



IRG-1 (clockwise from bottom left): Rachel Segalman, Megan Valentine, Thuc-Quyen Nguyen, Craig Hawker, Glenn Fredrickson, Christopher Bates, Michael Chabinyc, M. Scott Shell, Mengyang Gu.

IRG-1: Electrostatically Mediated Polymer Processing

"From a synthesis perspective, it's challenging to incorporate ions into materials, although some materials have achieved that," observes Bates in describing the research arc of IRG-1. He cites disposable diapers, which are made of a polymer material that has a lot of ionic charges added to it, as one example of the relatively few materials that effectively incorporate ions. Urine, which contains primarily water and salt ions, can be absorbed by the material thanks to negative charges in the polymer, which attract the strongly dipolar water molecules.

One of the projects in IRG-1 is aimed at compatibilizing plastics. Different types of plastics are used to make different kinds of products. During recycling, all of one type of plastic — indicated by the label on the container — gets melted down and reprocessed into a new material. "If you were to melt different kinds of plastic together, however, the result would be a bad product with terrible properties that behaved nothing like the original plastic," Bates says.

"Thus, when you recycle, you have to separate the different kinds of plastics. Now imagine that a plastic had a plus charge on it somewhere. That plus charge really wants to be near a minus charge. So, imagine another plastic that has a minus charge on it. If they are reprocessed in the same bin, they'll like each other enough, because of the plus and minus charges, to interact. The resulting plastic would have much better properties than different types of plastic would if they were co-processed today. You take advantage of the ions to bridge the dissimilarity in the products."

"The interactions in these systems are strong because water is not there to shield the forces between ions," explained **M. Scott Shell,** a chemical engineering professor and co-leader of IRG-1. "As a result, we believe these kinds of interactions can be used to produce new properties in materials that have yet to be explored. It is a beautifully simple but potentially powerful and underexplored materials-design approach."

The project is based on theory and simulations that chemical engineering and materials professor and IRG-1 member **Glenn Fredrickson** has developed, suggesting that if just a single positive charge is added to plastic A and one minus charge to plastic B, it's enough to make them compatible with each other. "You don't need a lot of charges," says Fredrickson. "You just need a sprinkling of charge on the dissimilar polymers, ideally with no counter-ions. The charges can be installed either at the time of polymer preparation, or by a reactive blending approach. Part of the IRG-1 effort will be determining the most effective approach, also factoring in cost constraints."

IRG-2: Bioinspired Plasticity

Materials science has long been dominated by solid-state crystalline materials, which have greatly benefited the world, enabling modern semiconductor electronics and major advances in steel and other building materials, according to **Omar Saleh,** professor and chair of the UCSB Materials Department and co-leader of IRG-2. "But those materials are not good at interfacing with soft, squishy humans," he says. "In our IRG, we are trying to learn from and be inspired by biology to think about how to produce new soft materials having new characteristics and corresponding new performance.

MRSEC Summer Interns


Juan Herrera

We asked the following four students about the value of their internships with MRL-affiliated faculty this past summer.

Juan Herrera, a fifth-year-senior mechanical engineering major at The University of Texas at El Paso, spent the summer working with postdoctoral researcher **Neil Brodnick** in mechanical engineering professor **Samantha Daly**'s lab. The work was part of a project for the U.S. Navy to characterize a new 3D-printed steel and determine its strength relative to traditional forged steel. He says that he found the lab meetings to be especially interesting: "Everyone presents their work, the group members ask each other lots of questions, and their questions show that everybody cares and is interested in others' work even if it's not related to their's. It seems to be ingrained in them that, just because something seems unrelated to your work now and you may know nothing about it, you never know when it will become relevant to you."


Holden Orias

Holden Orias, now a senior at Amherst University, did his internship in Craig Hawker's group, working closely with PhD student **Ronnie Garcia**. Orias created hydrogel networks and characterized how they degraded, a process related to developing new biodegradable "inks" for 3D printing.

He says he learned a great deal from the lab's open-ended research environment. "Ronnie talked to me a lot about how graduate students have to improvise and adapt," he said. "Having to stop and retool as we discovered new things or found that certain things didn't work made the experience more challenging and thought-provoking."

He also appreciated "having access to the genius of the people here and seeing how human and accessible they are." He recalled Hawker starting a mid-summer lab meeting by asking, "Did anyone do the 'Barbenheimer' double-feature over the weekend?"

KC Sims

KC Sims, a senior majoring in biochemistry at Jackson State University in Mississippi, spent the summer working primarily with her mentor, **Athenia Arias,** a graduate student in the lab of materials professor **Cyrus Safinya.** Sims contributed to a project aimed at developing a drug delivery system based on lipid protein synthesis.

While Sims is a confident student, she says that Arias's ability to explain complex concepts, and having just a few people in the lab, provided the personal attention unavailable in large classes and gave her the hands-on experience that grew her confidence in some areas. "A lot of times I've found in science that I 'know' something intellectually but am a little less confident when I have to apply it, so I've appreciated being able to get that practice to give me that confidence and that stronger foundation I wasn't able to gain before."


Essa Shamsan

Essa Shamsan is a fifth-year biochemistry major at UCSB who did his summer internship in the Dow Materials Lab through UCSB's California Alliance for Minority Participation (CAMP) program. His work involved developing synthetic peptoid coblock polymers. For him, the lab was a clarifying and skills-building experience.

"Working in the lab helped me realize that I enjoyed the experimental process enough to want to go to grad school prior to entering industry," he said. "That decision was clarified out of this experience. I also learned to think outside the box experimentally. In the beginning, it was hard to adjust to going from the kind of premade lab procedures we're given in our undergraduate labs to having to come up with a bunch of procedures and design the experiment. Working in a research lab has helped me fine-tune my ability to do both."

Polymers infused with water — *hydrogels* — will be a main focus for Saleh, his co-leader, UCSB assistant materials professor **Angela Pitenis,** and their collaborators in IRG-2. But they will also study non-polymer materials having various structures.

The water, which is what makes such materials hydrogels and enables them to be more bio-inspired, also adds a broad range of aqueous biochemistry, Saleh says, noting, "Adding water makes things much richer and more complicated and, therefore, gives us a lot to work with mechanically and chemically."

"The mechanical properties of soft materials are complex and not well understood, however," Saleh adds. "Our goal in IRG-2 is to explore new ways to create, analyze, and model the mechanics of such materials, and to embed new functions into them to improve and expand their mechanical properties, functionality, and application."

The work, like all of the research undertaken in the MRSEC, requires an interdisciplinary approach that challenges members to take their research in new directions. "The point of any IRG is that researchers should not be doing only what they're already an expert in, first, because that's not cutting-edge and, second, because NSF won't fund it," says Saleh. "The nine of us in our group are going to be stretched in some way while also bringing our own expertise. I work at the nanoscale, Angela works a lot at a larger scale with friction at interfaces, and we also have synthetic chemists, people with expertise in the interfacial mechanics of soft materials from a polymer perspective and the physics of biomolecules, as well as theorists.

"We're looking at things like living cells or tendons and noting that they are mechanically quite interesting, and that they couple that mechanical behavior with chemical behavior to create interesting feedback routines, in which a chemical reaction occurs and changes the mechanics, or a mechanical reaction occurs and changes the chemistry. Inspired by what living materials do, we want to create hydrogels that are slightly closer to biological materials and might lend themselves to use as medical devices or implants."

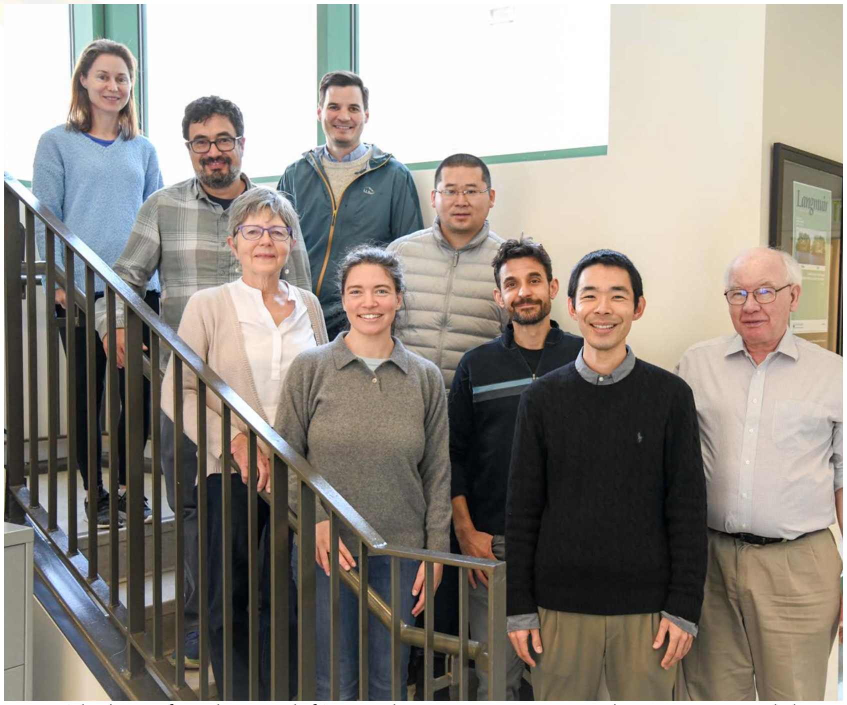
Shared Facilities and Instruments

More than one hundred faculty groups from UCSB and other universities, as well as nearly sixty companies, have used the shared campus facilities supported by the MRSEC. According to Ram Seshadri, "A disproportionate amount of our MRSEC funding goes to facilities [continuing the trend initiated by Cheetham in 1993]. We have six facility staff people and four PhDs who assist internal and external users, design and maintain experiments, and interpret data. We put money into facilities that could otherwise be used by faculty to pay PhD students and postdocs. It's an example of faculty sacrificing in their own labs in order to support the greater UCSB research community."

Further, he notes, "Facilities are not created for the exclusive use of the MRSEC, so the whole world is welcome to come and use them — and they do."

As an example of the benefits of the shared-facilities model, Seshadri explains that when a professor comes to UCSB and receives funds to purchase startup instruments for their lab, they might purchase a reasonably high-ticket item, which they then *contribute* to the facility, so that it belongs to everybody. After that, even the person who contributes the equipment pays the same user fee as everyone else to keep it maintained and pay support staff. In return, users, including PIs who contribute instruments, gain access to a broad range of other instruments that their startup funds would not allow them to purchase — instruments that are always maintained and for which training is always available. "No one professor working in a traditional, more 'siloed' environment could come close to acquiring the vast array of instruments we have at UCSB, many of which are operated by the MRSEC," Seshadri says.

> "The initial instrument came as part of Seshadri's startup, and four others were purchased to meet the heavy demand, something, Seshadri notes, 'that would never happen with the single-PI model.'"



IRG 2 (clockwise from bottom left): Angela Pitenis, Cristina Marchetti, Javier Read de Alaniz, Joan-Emma Shea, Matthew Helgeson, Yang Yang, Omar Saleh, Sho Takatori, Robert McMeeking.

The Materials Research Laboratory Building, home of the UCSB MRSEC.

While having no priority for instrument users can, Seshadri notes, "end up placing a lot of pressure on one instrument," the shared model allows UCSB to buy a second one or even a third one. That happened with the several low-temperature instruments that are in the low-temperature lab downstairs from Seshadri's office. The initial instrument came as part of Seshadri's startup, and four others were purchased to meet the heavy demand, something, Seshadri notes, "that would never happen with the single-PI model."

In 2020, following a meeting at UCSB in 2018 that brought together representatives from MRSECs and national laboratories, **Amanda Strom,** manager of the MRSEC's TEMPO Laboratory, joined Seshadri and colleagues at Cornell University and the University of Minnesota to co-author a paper, published in the *MRS Bulletin,* describing a broad array of benefits arising from a shared-facility model. Naming just a few of them, the authors wrote that shared facilities:

- Increase the visibility of accessible instrumentation, which aids in recruiting and retaining faculty and attracting competitive graduate students and postdoctoral fellows.
- Give interested faculty a voice on equipment acquisitions, avoid redundant purchases, and maximize equipment usage.
- Minimize expenses, increase revenue, and spread costs across a wide range of instrumentation.
- Enable institutions to build and leverage long-term relationships with vendors to access competitive pricing on equipment and maintenance.
- Serve as communication hubs for research groups and become a magnet for industrial collaborations and associated employment opportunities.
- Allow researchers to improve their knowledge of analytical science, making them more competitive in the job market.

In contrast to the self-interest and depleted resources underlying the famous economic theory known as "the tragedy of the commons," Seshadri refers to the culture of communal sharing, so highly developed and effectively implemented at UCSB and in the MRSEC, as "the *comedy* of the commons," adding, "I like to quote [UCSB chemical engineering professor and nuclear magnetic resonance expert] **Brad Chmelka,** who says that if another university wanted to hire him, he would need a $40 million startup to match all the shared facilities he has access to here."

Education and Outreach

The MRSEC model is aimed at efficiency, to get the most benefit by sharing resources, facilities, and intellectual muscle. Seshadri believes that UCSB stretches the model as far as possible, education and outreach being a case in point.

"At UCSB, we squeeze so much out of the MRSEC," he says. "For instance, we have two full-time staff — [academic coordinator] **Dotti Pak,** who is also a research scientist in the UCSB Marine Science Institute, and [research intern coordinator] **Julie Standish** — plus several other people to support the NSF-mandated education and outreach programs, which at UCSB are quite a bit larger than those run through most MRSECs."

The programs provide undergraduate research opportunities, graduate student and postdoctoral mentoring, transferable professional skills training, outreach to K-12 students and teachers, and community outreach.

Every summer, a group of student interns who are incoming university freshmen or undergraduates in university STEM programs spend a month working in a lab with an MRL-affiliated faculty member. The experience provides them with the opportunity to interact with graduate students and work closely with a PhD student or postdoctoral researcher. (See sidebar on page 21.)

The center leverages collaborations with other institutions that benefit undergraduate and graduate students, including the Partnerships for Research and Education in Materials, which provides student exchanges and research opportunities between UCSB and two minority-serving institutions, Jackson State University in Mississippi and The University of Texas El Paso; as well as another student-exchange partnership with Chalmers University of Technology in Sweden.

Few MRSECs can match the support for education and outreach services provided by (clockwise from front): Dotti Pak, Julie Standish, Mary McGuan, and Frank Kinnaman

Events such as Family Science Night and hands-on workshops reach nearly 4,000 K–12 students annually, more than 60 percent of whom are underrepresented minorities. Dozens of teachers also participate in MRSEC-funded research opportunities and workshops, building relationships with campus researchers and developing their science curricula. The MRSEC also supports more than fifty undergraduate interns who conduct research at UCSB each year. A survey of former interns showed that 65 percent of them went on to attend graduate school, 48 percent were female, and 39 percent were underrepresented minorities.

"I received an email the other day from a student who completed a summer program and recently graduated from college. She described the experience as 'life changing'," said Pak. "Our programs open doors by introducing participants to research experiences and to our research community. Feeling like a part of a supportive community is extremely important for everybody, especially underrepresented minority students."

Continuing a Long Arc of Success

Looking back on the center's extensive evolutionary arc from its founding as an NSF MRL to its continuation as a newly re-funded NSF MRSEC, inaugural director Anthony Cheetham says, "It is clear that the creation of the MRL at UCSB led to a step-change in both the quality and quantity of materials research on the campus. It was also pivotal in establishing UCSB as one of the world's leading centers for advanced materials. I never imagined that it would still be going as strong as ever in 2023, more than thirty years later. Long may it continue to prosper!"

Scan to learn more about the MRL's summer research program and its impact on student interns.