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Department of Materials Science and Engineering

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A Dynamic Field: Materials Science and Engineering

Materials science and engineering is one the most important of the engineering disciplines as it impacts nearly all the traditional fields of engineering. The discipline is concerned with the structure and properties of materials used in modern technology. This means that materials science and engineering is at the forefront of high technology for the simple reason that advancements in technology are the direct result of advances in materials. The importance of materials science and engineering is not recent. We only have to look at the names of eras to realize that materials have been instrumental in the advance of civilization: the Stone Age, the Bronze Age, the Iron Age. To many, we are now living in the Materials Age.

The field of materials science and engineering is directed towards understanding why materials behave the way they do, how materials are made, and how new materials with unique properties can be created. The study of materials science and engineering encompasses specific materials such as metals, ceramics, polymers, and semiconductors, and understanding how their structure, from the atomic level to that of common objects, influences mechanical, electrical, optical, chemical, biological and magnetic properties. What this means is that materials science and engineering impacts a wide range of modern technologies; from producing high-strength, lightweight aluminum alloys for new generations of aircraft to the addition of a layer of atoms on the surface of materials used in optical communications.

In this booklet, you will find descriptions of established areas with which you are already familiar, along with emerging fields that will impact your life in the very near future. In each case, materials science plays a key role in creating the technology.

- Structural materials, including metals, alloys, ceramics and composite materials, are among the most important materials in our daily lives and are therefore the easiest to take for granted. However, the field of Materials Science and Engineering actually evolved from detailed investigations, over the past century and a half, of the inter-relationships among the processing, "microstructure" and properties of structural materials. Investigations of this kind were the province of the area of research called Physical Metallurgy, and nearly every major Department of Materials Science and Engineering in the USA was originally a Department of Metallurgy. The alloys used in modern aircraft are marvels of modern physical metallurgy, yet if we could develop aluminum alloys capable of retaining high strength at relatively modest temperatures of 200 to 300 °C it would be possible to use them in supersonic aircraft flying at speeds exceeding mach 2. Similarly, if we could develop alloys or tough ceramics which remained strong at temperatures between 1000 and 1200 °C, we could then construct jet engines which were far more efficient and faster than those available today. These are among the objectives of research on structural materials.

- We already use optical communications in daily life. What you may not realize is that this technology is based on the field of photonic materials. Some of these materials efficiently transmit light, others generate light and still others detect light. In the near future we can expect new semiconductor materials, both hard and soft, that efficiently and inexpensively produce light in the green and blue parts of the spectrum to complement what we have today in the red. This means a range of new products for lighting homes and businesses, low power displays for lap top computers and cell phones, and even a new generation of “smart” traffic lights that use light-emitting diodes. Still further in the future is the promise of developing optical computing based on photonic materials.

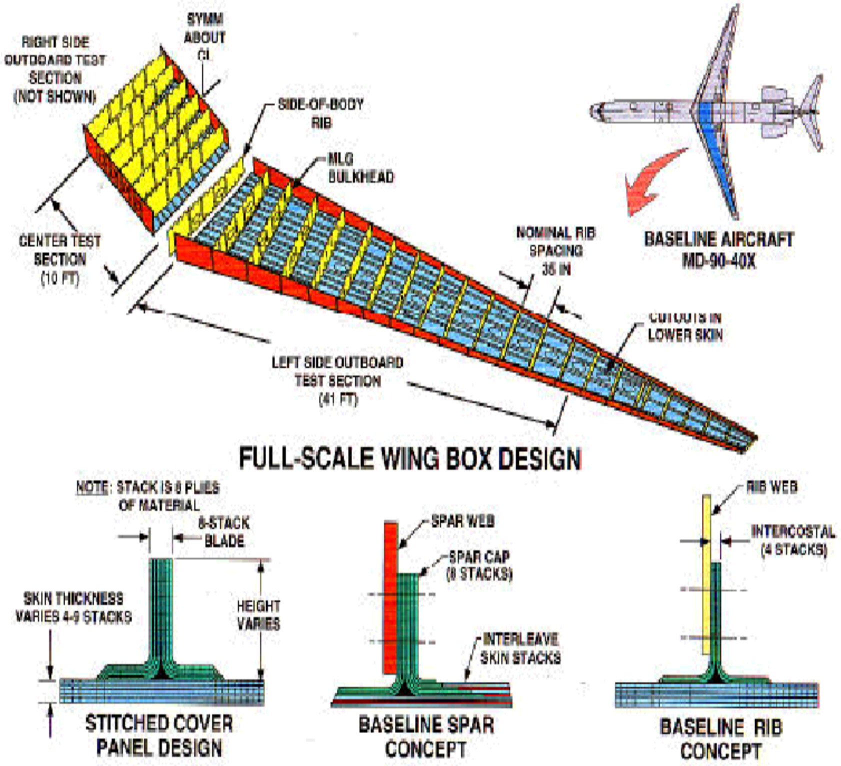
- The computer industry is critically dependent on materials science and engineering. From the microprocessors to the semiconductor memories, to optical and magnetic data storage, the ability to be smaller and faster is directly tied to developing new materials and creating the methods for reliable manufacturing at small dimensions. The future is an exciting one. We expect molecular electronics to revolutionize the sizes of individual logic elements and quantum computing to bring operations to the atomic level. Once again materials science and engineering will play a key role in creating the materials and processes that form the backbone of the technology.

- Materials science and engineering is already contributing to many areas of biotechnology. Some of these materials are hard, as needed for bone replacement, while others are soft, as needed for soft tissue repair. Still other materials are being developed for biomedical sensors and drug delivery. The field is very young and one of the most exciting directions is that of combining man-made engineering materials with naturally occurring materials.

The purpose of this booklet is to provide background for students--and their families and teachers--to better understand the importance of materials now and in the future. The field of materials science and engineering is underpopulated. There are estimates that some 60 percent of those who were trained as chemists or chemical engineers will eventually work on polymer materials, simply because there are not enough materials scientists being educated. Some of this expansion will occur because of the growth of biotechnology and the need to replace existing products with environmentally benign polymers. In future years, we can expect new polymers that will used in optical displays while other polymers will become inexpensive microprocessors that replace traditional silicon technology. It is hardly surprising that materials scientists are well positioned for contributing to science and technology. The current CEO at Intel is a materials scientist -- as was the former CEO. Students trained in materials science and engineering, from the B.S. to the Ph.D. level, are highly sought by Fortune 500 companies such as Hewlett-Packard, General Electric, IBM, Raytheon, 3M, Lockheed-Martin, DuPont, Xerox, Motorola, Monsanto, General Motors, Corning, Eastman Kodak……… we think you get the idea.

The descriptions in this booklet were prepared by faculty members in the Department of Materials Science and Engineering at the University of California Los Angeles. We hope you find the information useful. Please feel free to contact us for more information. The website address and telephone number for the Department are listed on the last page.

King-Ning Tu, Professor and Chairman of the Department



Composite materials offer the potential to reduce aircraft production and operating costs by reducing weight, increasing efficiency, and decreasing the cost of airframe structures. However, a cost-effective means for manufacturing large composite structures is required before composite wings can be used on commercial transports. The development of textile composite technology has been the breakthrough that has overcome the historical barrier issues of high cost and low damage tolerance associated with composite primary airframe structures. Our research efforts focus on developing new materials and innovative structural concepts to significantly advance today's state of the art for aircraft and engines.

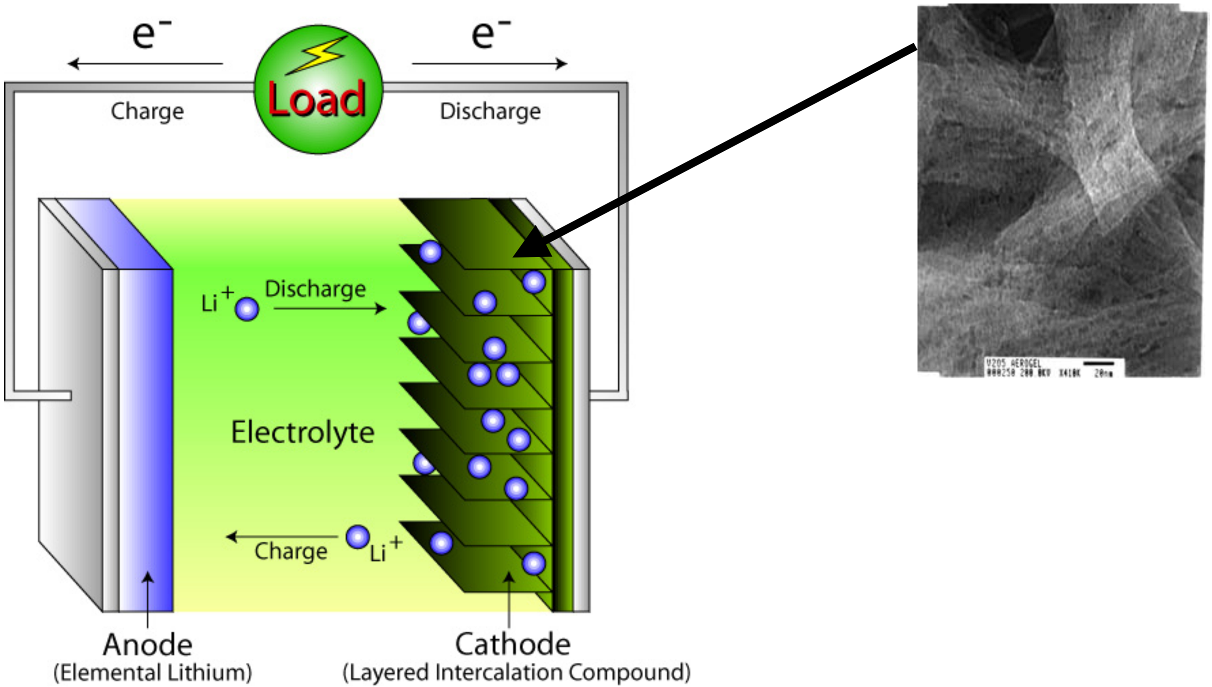
This research is being conducted in the group of Professor Jenn-Ming Yang (in collaboration with Professor H. T. Hahn in the Mechanical and Aerospace Engineering Department).

Conjugated polymers are a novel class of materials which combine the electrical and optical properties of semiconductors with the unique mechanical properties and processability of polymers. These materials can be used to fabricate thin film and large area polymer optoelectronic devices easily and at relatively low costs. Current research interests are in conjugated polymers and their applications in (opto)electronic devices, such as light-emitting diodes, photodiodes, and field effect transistors; with an emphasis on the study of the metal/polymer interface, invention of newer fabrication technologies and fabrication of flexible optoelectronic devices. Recently we have successfully demonstrated the patterning of polymer light-emitting logos and polymer multicolor devices using a hybrid inkjet printing technology. This hybrid inkjet printing technology, with its unique lateral patterning capability, uncovers a new direction for the fabrication of future polymer multicolor displays and other polymer based electronic devices. In addition to this excited invention, we have also invented a new polymer solution light-emitting device which bridges the liquid crystal display and polymer light-emitting displays. Our group currently have 7 students, 2 post-docs.

Pictures of polymer devices fabricated via hybrid ink-jet printing technology. Left, the picture of a polymer light-emitting logo. Middle, the picture of multi-color organic light-emitting diodes. Right, inter-digitated electrodes fabricated from conducting polymer.

A transparent blue-emission polymer SLED. Left, the picture of an unbiased SLED, it shows the transparent devices. Right, the picture of a biased SLED, it shows strong blue electrochemiluminescence.

This research is being conducted in the group of Prof. Yang Yang.



During the last decade, rechargeable or secondary lithium batteries have emerged as a popular choice for powering a number of portable electronic devices including cell phones, video cameras and computers. The diagram shows the basic operation of a secondary lithium battery. During discharge, lithium ions are transported through the electrolyte to an intercalation compound that has the ability to transport both lithium ions and electrons. The ion intercalation property is vital for the operation of lithium batteries. For most materials this property depends upon ion insertion into relatively open two-dimensional planes. During charge, lithium ions in the intercalation compound are removed from the structure, transported through the electrolyte and deposited on the lithium electrode.

There is a continuing need to create new materials with improved lithium ion insertion properties because this process is directly related to the energy density of the battery. Our research has focused on the use of vanadium oxide aerogels (insert). The characteristic ribbon morphology of this material at the nanometer level facilitates lithium ion insertion. In addition, we prepare this material with a high surface area so that it can benefit from ion insertion at the surface. Our results with vanadium oxide aerogels indicate that it can provide up to three times the energy density of commercial materials.

This research is being conducted in the group of Prof. Bruce Dunn.

Synchrotron Radiation Study of Sn Whiskers Grown on Pb-free Solders Used in Electronic Packaging Technology

The use of solder to connect parts in electrical circuit is ubiquitous in computers as well as in movable, handheld electronic devices. The conventional PbSn solder is of environmental concern. Lead(Pb) free solder is currently of immense interest in electronic packaging industry. In US, there are four anti-Pb bills pending in the Congress. In European Union, the Waste from Electrical and Electronic Equipment (WEEE) has a Directive calls for a ban of Pb in all electronics by 2008. In Japan, most of the major electronic companies have made commitments to go Pb-free as early as 2001 in their products. The Pb-free solders are Sn-based and are known to grow Sn whiskers. A long whisker may provide an electrical short in a device. In Fig. 1 where a whisker is shown to connect two legs of a leadframe, which is used to package a Si chip. The surface of the leadframe was coated with a layer of Pb-free solder. Whiskers grow from the solder surface. The diameter and length of the long whisker are about 3 microns and 300 micros, respectively. Fig. 2 shows a synchrotron radiation analysis of the whisker and the solder around the root of whisker. Since the diameter of the synchrotron radiation beam is about 0.8 to 1 micron, we are able to analyze the whisker and every grain in the solder. Using the lattice parameters of the whisker (Sn has a body-centered tetragonal lattice) as stress-free references, we have determined that the grains surrounding the whisker were under compression. The growth of the whiskers is to release the stress in the Pb-free solder. The analysis was carried out at Advance Light Source in National Lawrence Berkeley Laboratory with the assistance of Dr. N. Tamura. The project is supported by SRC/NSC and monitored by Dr. Harold Hosack. The whisker samples were from Dr. Luu Nguyen, NSC.

This research is being conducted in the group of Prof. King-Ning Tu.

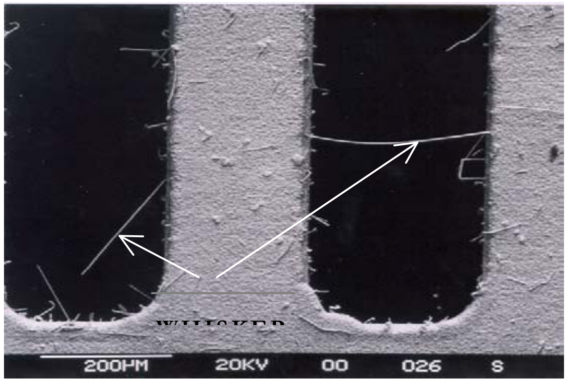


FIGURE 1. WHISKER ON LEADFRAME

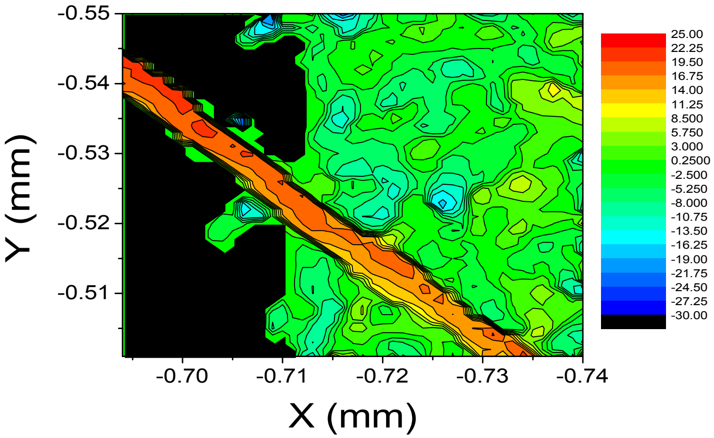
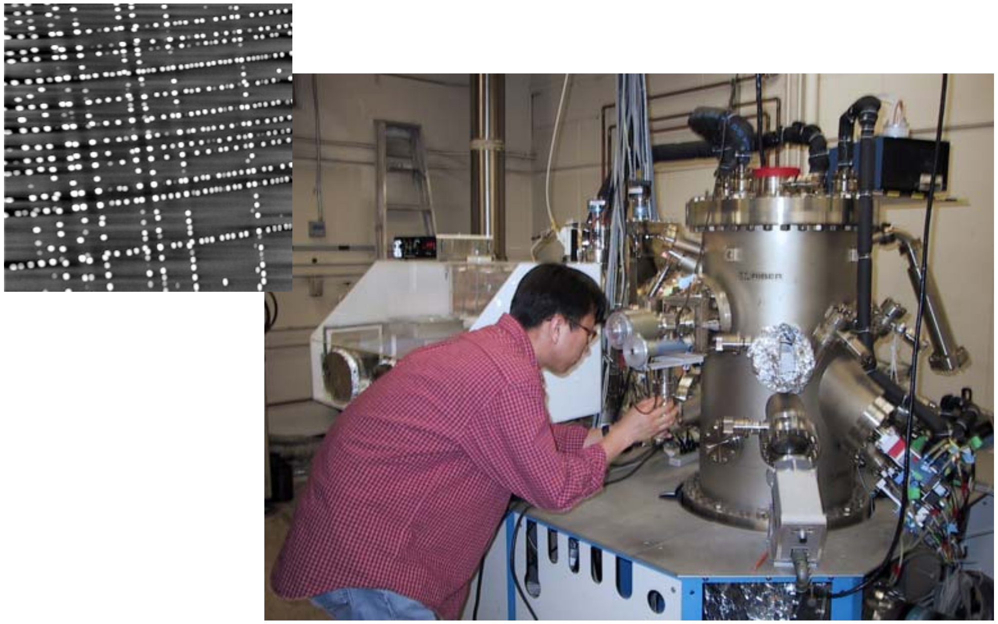


FIGURE 2. STRESS DISTRIBUTION ON PB-FREE SOLDER MEASURED BY SYNCHROTRON RADIATION



Molecular beam epitaxy (MBE) is a crystal growth technique that allows control of composition and other processes during crystal growths at sub-atomic layer level, thereby enabling a new generation of semiconductor devices to be fabricated that were impossible in the past. Today, epitaxy has become one of the key components in the microelectronics industry. In our group, there are research activities in MBE growths of Ge/Si and III-V compound semiconductors. Quantum dots of nanometer dimension (figure inset is a 5 μm x 5 μm scan of a quantum dot sample surface using atomic force microscopy) are being studied with emphasis on the understanding of their growth mechanism, quantum dot size and shape uniformity, and their placement regularity. Successful outcome of our research will lead to infrared lasers with controllable wavelength with applications in fiber optic communication, pollution monitoring, and medical fields.

This research is being conducted in the group of Prof. Ya-Hong Xie.

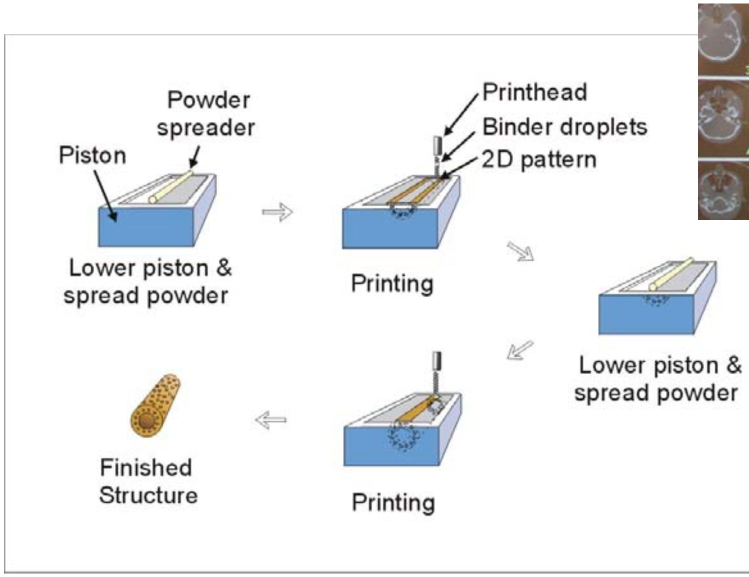


Fig A

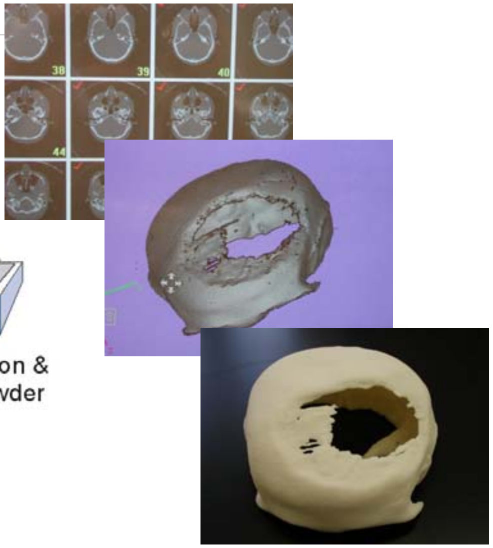


Fig B

Three Dimensional Printing is a room temperature, solid freeform fabrication technique which constructs three dimensional objects by ink-jet printing liquid binder droplets onto thin powder layers. Briefly, a thin layer of fine powder is first spread evenly across a piston, and the powder particles are selectively joined by ink-jet printing liquid binder droplets. The piston is then lowered, the next layer of power is spread and "printed". The cycle is repeated until the entire 3D structure is reconstructed.   Removal of the unbound powder reveals the fabricated structure (Fig A). Complicated macroscopic features such as internal voids, cantilevers, and narrow tortuous paths are simply reduced to a stack of simple 2D features such as circles, lines, and points.   The applications of this technique with biomaterials is being investigated for pre-surgical modeling (Fig. B), anatomically accurate implant prostheses , and tissue engineering devices.   The materials engineering issues depend on the biomaterial of interest, and include powder fabrication, powder spreading, ballistic effects, binder imbibition into porous media, binder-powder interactions, densification, and sterilization.

This research is being conducted in the group of Prof. Benjemin Wu.

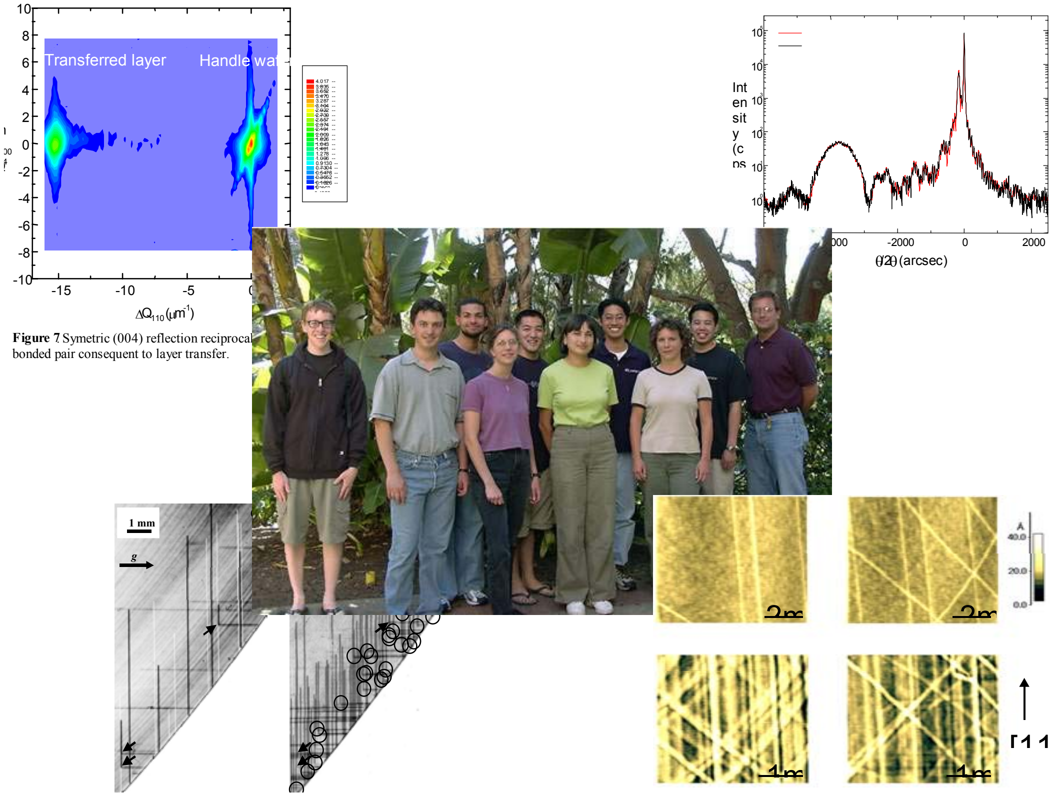


Figure 7 Symetric (004) reflection reciprocal
bonded pair consequent to layer transfer.

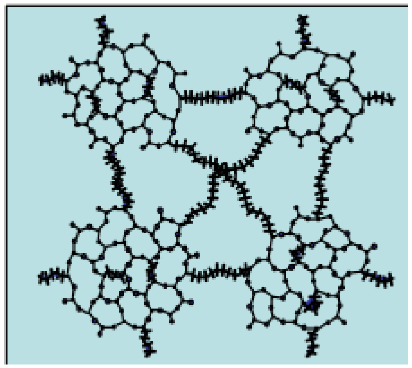
Epitaxial heterostructures provide for advanced electronic and optoelectronic devices. The manipulation of strain in these structures extends their utility to new applications. Research activities in our department focus on the relationship between structural and chemical irregularities in solid state electronic materials and the effect that these defects have on the performance of devices fabricated from these materials. We primarily collaborate with industrial and government laboratories to study these issues. In particular, we use non-destructive techniques to study the evolution of defects in these structures. Our main characterization techniques include double crystal x-ray topography and reciprocal space mapping through triple axis x-ray diffraction. Our research provides insight into the control of strain and defects for materials systems ranging from silicon through gallium arsenide and indium phosphide to silicon carbide.

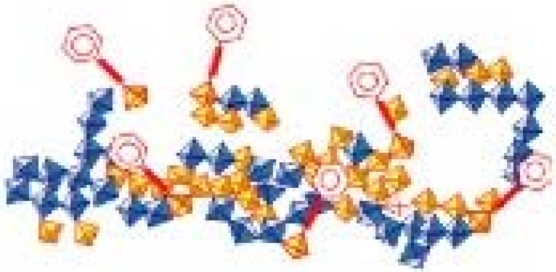
This research is being conducted in the group of Prof. Mark S. Goorsky.

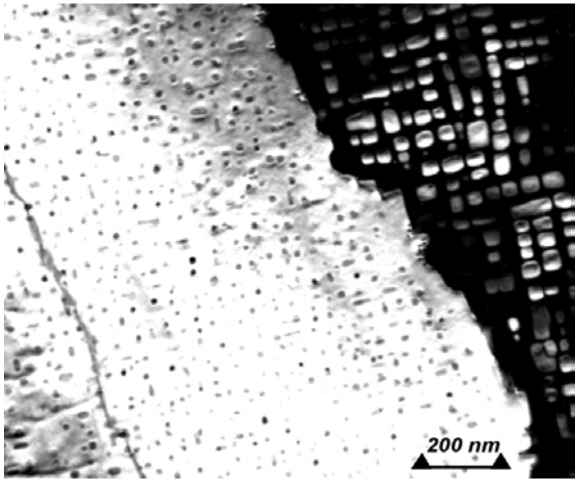
New Engineering materials- The Organic-Inorganic hybrids

For many years, engineering materials had been divided into metals, ceramics, semiconductors and organic plastics. Each of these is known to have unique properties. For instance, metals are electrical conductors whereas ceramics and plastics are insulators. Then it was discovered that optically, plastics can behave like semiconductors. Inorganic ceramics and oxide glasses are hard and brittle whereas plastics are flexible. More recently, a new class of engineering materials, the organic-inorganic hybrids, has been prepared by a low temperature liquid solution methods known as the sol-gel process. These new materials not only can have some properties better than ceramics and plastics but they also have unique properties not possessed by all previously know materials of engineering. The structures are made up of chemically joined organic and inorganic aggregates as shown in the picture. Because they are made via liquid solutions, they can be applied as coatings or cast into any shape. Chemicals such as organic dyes and colloidal particles can be added to the solution to create new nanocomposites. They can be fabricated into sheets with aligned channels or tiny spheres with controllable minute holes. Their potential uses are limitless in diverse fields such as the controlled release of drugs in the human body, the healing of bones and soft tissues in the form of "scaffolds", microsensors, high temperature stable rubbers, and much more. They have even been successfully tested as coatings to preserve priceless antiquities such as the mosaic sculpture of a European cathedral shown in the photograph here.

This research is being conducted in the group of Prof. J. D. Mackenzie.







Dark-field transmission electron micrograph of the precipitate structures in a Ni-22at.% Al alloy aged at 700 °C. The bright, squarish-shaped features in the region at the right (dark background) are particles of the Ni_3Al phase. This phase is the main phase at the left-hand part of the photo, and appears as a bright background. The spots in this background are small precipitates of the Ni-Al solid solution phase. Their growth is obvious much slower than the growth of the Ni_3Al precipitates in the solid solution.

The influence of internal and applied stress on the morphology, spatial correlations and kinetics of coarsening of fully coherent Ni3X-type precipitates in binary Ni-X alloys (X = Al, Ga, Ge or Si) is currently under investigation. These alloys are model Ni-base superalloys, which are used as turbine blades in jet engines for aircraft and turbines for the generation of electricity. Apparatus has been designed and constructed for annealing single-crystal specimens of these alloys for times up to 150 h at temperatures of 650 °C under compressive stresses up to 150 MPa. This research program makes heavy use of transmission electron microscopy to observe the precipitate microstructures, and utilizes special software to measure their sizes, size distributions and shapes. The inverse problem, i.e. coarsening of the disordered solid solution in a matrix of the ordered phase is also being investigated in the Ni-Al, Ni-Ga and Ni-Ge alloy systems. The photograph above shows the kinds of microstructures found in a Ni-22% Al alloy which initially contained large regions of solid solution of both phases and heat treated to precipitate both phases in each other. It is evident that precipitates of Ni_3Al grow much faster in the disordered Ni-Al solid solution than precipitates of the disordered phase grow in the ordered Ni_3Al matrix. This is but one of the surprises arising from this research project. The results of these investigations are expected to provide numerous insights into the relative roles of the lattice mismatch, the elastic modulus mismatch and the interfacial free energy which govern the evolution of microstructure in this class of alloys.

This research is being conducted in the group of Prof. Alan Ardell.