Ohmer[5,6] directly measured the birefringence of $ZnGeP_2$. This work invalidated the speculation of Andreev et al.[7] and re-established the phase angle anomaly.

In the same paper Andreev et al.[2] report that heating the sample to 160–180°C produces a broad maximum in conversion efficiency due to an increasing birefringence with increasing temperature. They clearly reject Bhar's conjecture of a rise in temperature as the source of the anomalously low phase matching angle at room temperature. The results of CO_2 SHG experiments performed by Schunemann[4] at 77 K (liquid nitrogen temperature) are in even more remarkable disagreement with predictions and Bhar's speculation. Schunemann found that the SHG at 77 K was twice as efficient. The angle was 63.6° for 9.3 μm, only 2.3° larger than the room temperature value. Even at a temperature of -196°C, the angle is still 2.9° below the predicted room temperature value of 65.5°.

One possible source of the anomaly may be nonlinear absorption effects. SHG experiments in Te[7] and $CdGeAs_2$[8] indicate that the best performance occurs at angles slightly off of the phasematching angle. In these works, time resolved pulse shape measurements clearly indicate that performance saturates due to an interaction between the second harmonic and photo-induced free carriers. The same situation should exist for $ZnGeP_2$.

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Melvin C. Ohmer
Air Force Research Laboratory
Ravindra Pandey
Michigan Technological University

RESEARCH/RESEARCHERS

Alicyclic Polymers Designed for 193-nm Wavelength Resist Applications

Photoresist compositions designed for 193-nm lithography by scientists from the Department of Chemistry and Biochemistry at the University of Texas—Austin were fabricated from a series of cycloaliphatic co- and terpolymers of carbo-*tert*-butoxynorbornene, norbornene carboxylic acid, methyltetracyclododecene carboxylic acid, 5-norbornene-2-methanol, and maleic anhydride, which were synthesize by free radical, Pd(II)-catalyzed addition and ring-opening metathesis polymerization (ROMP) techniques. The purpose of developing lithographic technologies with reduction in exposure wavelengths is to continue to provide higher resolution. While 193-nm lens systems have been developed, the damage threshold for the glass limits the exposure power that can be delivered to the wafer, so highly sensitive resists are necessary to enable 193-nm imaging technology. According to a report published in the November 1998 issue of *Chemistry of Materials*, the scientists at Texas have demonstrated resists with high sensitivities of 3–15 mJ/cm² with 0.16 μm features resolved.

The resist solutions were spin-coated at 2500 rpm to produce ~0.7-μm thick films on 8 in. double-polished silicon wafers. Following exposure to doses ranging from 0 to 50 mJ/cm² on a 248-nm or 193-nm excimer laser stepper, the wafer was baked for 60 s at 150°C with postexposure bake temperatures of 140, 130, and 120°C.

Lithographic evaluation shows that resists formulated with poly(CBN-*co*-NBCA) experienced cracking and adhesion problems; specifically features with dimensions below 0.6 μm lose adhesion to the substrate. The scientists conclude that resists made from free radical polymers containing maleic anhydride units show the best resolution and adhesion; those made from Pd(II)-catalyzed addition polymerization suffer from adhesion problems; and resists formulated from ROMP-derived polymers have poor resolution and suffer from phase incompatibility with conventional onium-based photoacid generators.

NSF Invests $10 Million in New Engineering Research Centers

The National Science Foundation (NSF) has invested $10 million to fund the first year of new Engineering Research Centers. Each of the centers will receive $2 million in the first year from NSF, leveraged by support from industry, state governments, and partnering universities. NSF will support the centers for five years, after which the support agreement is subject to renewal. Among the new centers is the Research Center for the Engineering of Living Tissues at Georgia Institute of Technology, which will focus on the development of substitutes, both natural and synthetic, for lost or damaged living tissue. For tissue engineering, researchers must integrate engineering with molecular and cell biology. This integration depends on developing ways to engineer cells that can respond to physical demands and materials that can respond to biological demands. In addition, the Center for Advanced Engineering Fibers and Films (CAEFF) has been established at Clemson University. CAEFF will explore how fiber and film industries can speed development of new products through innovative computer modeling.

Carbon Nanotubes Aligned on Glass

Researchers at the University of Buffalo have reported the growth of completely aligned carbon nanotubes for flat-panel displays. These carbon nanotubes, described in the November 6, 1998 issue of *Science*, are elongated, tubular versions of C_{60}, the molecule known as the buckyball.

"Our nanotubes are beautifully aligned, they grow at relatively low temperatures, and they are grown on glass," said Zhifang Ren, associate professor of physics and chemistry at the University of Buffalo.

According to Ren, carbon nanotubes are at least 100–1,000 times stronger than steel and offer high stability and excellent electron-emission capabilities. The combination makes them suitable for use in flat-panel displays such as television and computer screens.

"In a conventional television, a high-voltage electron gun is constantly in motion, bombarding each pixel on the screen," Ren said. "But in order to have enough room for the gun to scan the whole length and breadth of the screen, you need about a foot."

Flat-panel displays require less than a millimeter of space between the carbon nanotubes, which act as the electron emitters, and the phosphor screen. Each pixel in the flat-panel display is an electron source, and the need for scanning and that distance between the electron source and the screen are eliminated.

Technical problems have prevented flat-panel displays based upon nanotubes from advancing to the development stage. Because electrons come out from only the tip of each tube, all the nanotubes must be positioned exactly perpendicular to the substrate on which they are grown. If the alignment is not good, then good electron-emission properties cannot be obtained.

Previously published work on carbon nanotubes has shown poor alignment. Previous work also involved growing carbon nanotubes on materials other than glass, which was necessary because of the high temperatures required for the syn-

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thesis of the nanotubes.

Glass is the preferred material for monitors because it costs only a few dollars compared to several hundred dollars for silicon-based materials. However, to use glass as the substrate, synthesis temperatures must be below 650°C, the point at which glass begins to deform. Ren believes that the use of ammonia, instead of nitrogen, during synthesis enabled his team to grow the nanotubes at such comparatively low temperatures. He said that the ammonia helps the disassociation of acetylene, which is necessary during the synthesis of the carbon nanotubes.

Compliant Universal Substrate Matches Epitaxy Thin Film Grid Grown on Top

A joint research team from the University of Houston, Applied Optoelectronics Inc. (AOI), and Cornell University has developed a technique called the "compliant universal substrate" for creating epitaxial thin film devices. In traditional epitaxy, the quality of epitaxial layers is critically dependent upon matching the substrate's crystalline structure. Materials requiring substrates with different "grid sizes" cannot be used, greatly limiting researchers' options.

The compliant universal substrate is similar to a grid printed on a piece of rubber loosely bonded to a conventional substrate. It expands or contracts to match the grid of the epitaxy thin film grown on top of it. By eliminating concerns about matching the grids on the underlying conventional substrate, the universally compliant substrate increases the choices of epitaxy thin films/substrate combinations for optoelectronic applications. As reported by Chau-Hong Kuo of the Space Vacuum Epitaxy Center (SVEC) at the North American Molecular Beam Epitaxy Conference at University Park in early October, 1998, the device fabricated is an optically pumped mid-infrared (ir) laser based on InAs/GaInSb type-II quantum wells grown on a compliant substrate sitting on a GaAs substrate. Kuo said, "These type-II quantum wells have more than 7% lattice mismatch with the GaAs substrate. Without the compliant substrate in between, the difference in lattice size will result in too many defects in the quantum wells for reliable devices." The mid-ir laser fabricated on the compliant substrate has a differential quantum efficiency of 7.2% which is comparable to the devices grown on the nearly matched GaSb substrates. However, fabricating mid-ir lasers on GaAs-based compliant substrate provides a better heat sink for the laser, achieving significantly higher total output power.

According to Shin-Shem Steven Pei, a UH electrical engineering professor and associate director for research at SVEC, "The demonstrated device is a mid-infrared laser emitting at 4-μm wavelength which has many important industrial, medical, and military applications such as monitoring of industry and pollution gases, medical diagnosis, and heat-seeking-missile countermeasures."

Chih-Hsiang Thompson Lin, President of AOI, said, "Optoelectronic research has recently focused on short wavelength (yellow, green, blue, and ultraviolet) and mid-ir light sources which are not based on conventional semiconductor materials such as silicon or gallium arsenide. However, to synthesize new single-crystal substrates with the same lattice size as these, new materials are not only technologically difficult, but also extremely costly in most cases. Consequently, the very limited availability of substrate materials has severely limited the types of compound semiconductors people can use to grow new single-crystal thin film for novel device applications, or the quality of the semiconductor grown on lattice-mismatched substrates."

Microwaves May Provide Early Detection of Breast Cancer

A breast cancer imaging technology that uses microwaves instead of x-rays to detect breast tumors is being developed by a team of researchers at Northwestern University, the University of Wisconsin—Madison, and Interstitial, Inc., an Evanston-based startup company.

Unlike x-ray mammography, which shadows potential tumors by passing high-energy ionizing radiation through the highly compressed breast to expose film on the other side, the microwave approach uses a miniature antenna contacting the skin surface to bounce very low energy, non-ionizing microwave pulses off potential tumors, without breast compression.

The device was envisioned by Interstitial chair Jack Bridges, who knew that microwaves interact with human tissues primarily according to water content. Because malignant tumors have a much higher water content than normal breast tissues, he conjectured that microwaves could provide the basis for a highly sensitive detection system, especially if an antenna could be constructed that exploits the "whispering gallery" phenomenon familiar to visitors of science museums. Bridges envisioned that a tumor's microwave echo could be tuned in at the source of the radar pulse, while the noisy clutter from the complex surrounding normal tissues would be rejected.

Allen Taflove, professor of electrical and computer engineering at Northwestern's Robert R. McCormick School of Engineering and Applied Science, directed extensive supercomputer modeling of the microwave sensor and aided in the development of the technology. Susan Hagness, a former graduate student in Taflove's laboratory, used Cray Research, Inc. supercomputers to model the microwave detection technology. Hagness presented the results from the supercomputer simulations of the microwave tumor detection system in October 1997 in Chicago at the IEEE International Conference of the Engineering in Medicine and Biology Society, and in June 1998 in Atlanta at the IEEE Antennas and Propagation Society International Symposium. An article describing initial results was also accepted in the December 1998 issue of *IEEE Transactions on Biomedical Engineering*, and is scheduled to appear in early 1999 in *IEEE Transactions on Antennas and Propagation*.

"On the Cray supercomputers, we were able to simulate embedding a tumor within randomly oriented veins and mammary ducts and lobes in the breast," said Hagness, who is now an assistant professor of electrical and computer engineering at the University of Wisconsin—Madison and is continuing to work on the technique's development. "We found that the ability of the microwave sensor to detect small tumors was only slightly affected by natural variations in the properties of the breast tissues."

A complete microwave tumor-detection system will consist of a sensor and a computer processor. The microwave sensor will be a small flat panel containing an array of miniature antennas placed on the surface of the breast. Bridges said the microwave signal can be focused within the breast, and the entire breast can be electronically scanned under software

SBIR Update

Collagen Matrix, Inc. (Franklin Lakes, New Jersey) has received a Small Business Innovation Research (SBIR) Fast Track grant from the National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health (NIH). The grant is for the development of resorbable collagen-based reference materials for tissue engineering research.

control to create a three-dimensional microwave image.

A laboratory prototype of the microwave sensor was built mostly with off-the-shelf components. The device was successfully tested on a "phantom"—a simulated breast consisting of materials that share key microwave properties of normal breast tissues. A tiny simulated tumor was embedded within the breast phantom and was located using the microwave sensor. The microwave sensor has not yet been tested on humans.

The breast-phantom tests showed that the laboratory prototype sensor could easily detect 0.25-in. simulated tumors embedded about 1.5 in. deep. With modest equipment improvements, even smaller tumors at least two inches deep could be detected. These results were consistent with those developed by the supercomputer simulations.

Interstitial was awarded two U.S. patents this year on the new breast tumor radar technology. Several additional patents are pending.

Supercomputer Simulation of Magnetism Achieves 1 Teraflop Performance

A team of scientists from Oak Ridge National Laboratory working with the National Energy Research Scientific Computing Center (NERSC) at the Lawrence Berkeley National Laboratory performed a 1,024-atom first-principles simulation of metallic magnetism in iron, which ran at 657 Gigaflops on a 1024-processor Cray/SGI T3E supercomputer. The researchers achieved a run up to 1.002 Teraflops.

Malcolm Stocks, a scientist in Oak Ridge's Metals and Ceramics Division and leader of the project, said, "One of the goals of this project is to address critical materials problems on the microstructural scale to better understand the properties of real materials. A major focus of our research is to establish the relationship between technical magnetic properties and microstructure based on fundamental physical principles."

The performance runs were performed during the development of a new theory of nonequilibrium states in magnets. The new constrained local moment (CLM) theory places a recent proposal for first principles Spin Dynamics (SD) from a group at Ames Laboratory on firm theoretical foundations. In SD, nonequilibrium "local moments" (for example, in magnets above the Curie temperature, or in the presence of an external field) evolve from one time step to the next according to a classical equation of motion. As originally formulated, the fundamental problems with SD stemmed from the fact that the instantaneous magnetization states being evolved were not properly defined within the Local Spin Density Approximation to the Density Functional Theory (LSDA), the framework of most modern quantum simulations of materials.

The CLM theory formulates SD within constrained density functional theory. Local constraining fields are introduced, the purpose of which is to force the local moments to point in directions required at a particular time step of SD. A general algorithm for finding the constraining fields has been developed. The existence of CLM states has been demonstrated by performing calculations for large (up to 1,024-atom) unit cell disordered local moment models of iron above its Curie temperature. In this model, the magnetic moments associated with individual Fe atoms are constrained to point in a set of orientations that are chosen using a random number generator. This state can be thought of as being prototypical of the state of magnetic order at a particular step in a finite temperature SD simulation of paramagnetic Fe.

Semitransparent Bark Offers Alternative to Synthetic Materials in Forming Rubber

Researchers at the University of California—Santa Barbara, UC—Los Angeles, and the Santa Barbara Botanic Garden have found that the semitransparent bark of birchbark cherry (*Prunus serrula*) represents a viable alternative material to commercial synthetic films for forming rubber. According to the scientists' report published in the November 1998 issue of *Chemistry of Materials*, bark films were peeled from three *Prunus* branches and sliced into sections 5-mm wide × 25-mm long. Each bark sample is comprised of two (outer) layers of phellem and an inner layer consisting of the secondary phloem. Under scanning electron microscopy, the bark films show to be made up of interconnected elongated phellem cells. Various studies were performed on the samples, including optical birefringence, surface morphology, Fourier transform infared, elemental analyses, thermogravimetric analysis, and tensile testing.

Various plasticizing agents, including ethylene glycol and poly(ethylene glycol) (PEG 200), have been applied to modify and enhance the mechanical properties of the bark. Unlike the effect of plasticization on other types of wood in which swelling is induced in three directions, the agents cause the *P. serrula* bark to shrink along the tangential axis, with PEG producing a larger effect on the dimensional changes than ethylene glycol. According to the researchers, the "plasticizing agents help to relax the stretched and aligned cell walls caused by tree growth." Upon testing the mechanical properties of the plasticized bark from the outer layer of a seven-year-old branch, the researchers found that, along the fiber axis, "tensile strength increases 55% and Young's modulus increases 100% compared to the original sample."

E.O. Lawrence Awards Honor Advances in Atomic Energy

Laura H. Green, a professor of physics at the University of Illinois, Urbana-Champaign and a member of the Materials Research Society, has been chosen as one of six recipients of the E.O. Lawrence Awards. Named for the late Ernest Orlando Lawrence, the inventor of the cyclotron, the awards were given for outstanding contributions in the field of atomic energy. Each recipient receives a gold medal, a citation, and $15,000.

For her award, Green has been honored in the Materials Research category for pioneering experiments that clarify the behavior of electrons at the surfaces of low- and high-temperature superconductors, and what happens to the electrons when they travel into other materials.

The other five awards are as follows:

- Nuclear Technology: **Dan G. Cacuci** (University of Karlsruhe, Germany; University of Virginia, Charlottesville; and University of Michigan, Ann Arbor) honored for his methodology for measuring and analyzing the uncertainties of nonlinear mathematical models of

Review Articles

The October 1998 issue of *Review of Scientific Instruments* features a review article on "Phase Measurement of Light Absorption and Scatter in Human Tissue," by B. Chance and N. Ramanujam (University of Pennsylvania), M. Cope (University College London), E. Gratton (University of Illinois at Urbana-Champaign), and B. Tromberg (University of California—Irvine).

The November 26, 1998 issue of *Nature* carries a review article on "The Relationship Between Liquid, Supercooled and Glassy Water," by O. Mishima (National Institute for Research in Inorganic Materials, Japan) and H.E. Stanley (Boston University).

processes and systems;

- Life Sciences: **Joanna Fowler** (Brookhaven National Laboratory) for devising innovative ways to attach radioactive isotopes to molecules for research in biology and medicine;
- Physics: **Steven Koonin** (California Institute of Technology) for his broad impact on nuclear and many-body physics, particularly his supercomputer calculations related to predicting the properties of atomic nuclei on earth and in the stars;
- Environmental Science and Technology: **Mark Thiemens** (University of California—San Diego) for his development and application of new isotope effects to the atmosphere and his discovery of a class of isotope effects that reveal the photochemical coupling of carbon dioxide to ozone in the atmosphere;
- Chemistry: **Ahmed Zewail** (California Institute of Technology), for discovering new ways to view molecular reactions using extremely short pulses of laser light.

AVS Announces 1998 Award Recipients

The American Vacuum Society has selected six major award recipients for 1998.

- Materials Research Society (MRS) member **David G. Cahill** (University of Illinois) received the Peter Mark Memorial Award for his contributions to the atomic level understanding of thermal conductivity in thin films and surface roughening/ smoothing mechanisms during film growth and etching. This award is presented to a young scientist or engineer for outstanding theoretical or experimental work, some of which must have been published in the *Journal of Vacuum Science & Technology*.
- MRS member **David E. Aspnes** (North Carolina State University) received the Medard M. Welch Award for novel applications and creative development of optical methods and effects for research on thin films, surfaces, and interfaces, which have significantly advanced the understanding of electronic materials and processes. The award recognizes outstanding research in the fields of interest to the AVS.
- **Paul W. Palmberg** (formerly of Physical Electronics), was honored with the Gaede-Langmuir Award for his inventions that resulted in the development of practical energy analyzers for surface analysis by Auger-electron spectroscopy and x-ray photoelectron spectroscopy. The award recognizes outstanding discoveries and inventions in the sciences and technologies of interest to the AVS.
- **Peter J. Clarke** (Sputtered Films) received the Albert Nerken Award, based on invention, development, and commercialization for the conical magnetron sputtering source, known as the S-Gun, and the continued development of commercial-scale sputter deposition technology. The award recognizes outstanding contributions to the solution of technological problems.
- **Hasan Fakhruddin** (Indian Academy for Science, Mathematics, and Humanities) was honored with the John L. Vossen Memorial Award for developing a demonstration experiment for measuring the refractive index of air using a vacuum chamber. The award recognizes active high-school or middle-school science teachers in the United States, Canada, or Mexico for development of outstanding demonstration experiments.
- **David A. Lubelski** (Purdue University) received the George T. Hanyo Award for outstanding performance in technical support of research or development in the areas of interest to the AVS.

Twenty AVS members also were honored with AVS Fellowship. These include MRS members **Scott A. Barnett** (Northwestern University), **David G. Cahill** (University of Illinois), **David B. Fraser** (formerly of Intel), **D. Wayne Goodman** (Texas A&M University), and **Gottlieb S. Oehrlein** (SUNY, Albany). MRS member **Alexander Mamishev** (Massachusetts Institute of Technlogy) was one of nine recipients of AVS graduate research awards.

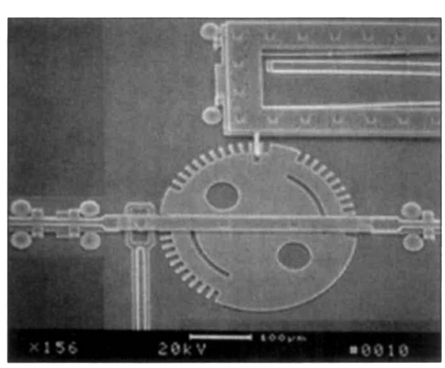
Minuscule Combination Lock Strengthens Security of Computer Firewalls

Sandia National Laboratories researchers used microelectromechanical system (MEMS) technology to develop the Recodable Locking Device, mechanical hardware intended to preserve the integrity of computer firewalls. The silicon device, designed by Frank Peter, an engineer in Sandia's Electromechanical Engineering Department, is a series of tiny notched gears that move to the unlocked position only when the correct code is entered.

The Sandia Microelectronics Development Laboratory used Peter's design to build a working device, which consists of a series of six code wheels, each less than 300 μm in diameter, driven by electrostatic comb drives that turn electrical impulses into mechanical motion. The lock owner sets a lock combination to any value from one to one million. As reported in the November 14, 1998 issue of *Science News*, the device, which is about 9.4 mm × 4.7 mm, consists of two sides, the user side and the secure side. To unlock the device, a user must enter a code that identically matches the code stored mechanically in the six code wheels. If the user makes even one wrong entry, the device mechanically locks by throwing a switch that interrupts the flow of electric current or light through the device and does not allow any further tries until the owner resets it from the secure side.

The six gears and the comb drives can be put on a small chip for incorporation into any computer, computer network, or security system. Because the chip is built using integrated circuit fabricating techniques, hundreds can be constructed on a single 6-in. silicon wafer.

Sandia recently filed for a patent for the mechanism, and the first working units were fabricated in July 1998.



One of six code wheels in the Recodable Locking Device shown in an enabled position after the correct code has been entered. The wheel is 300 μm in diameter.

Nanometer-Scale Local Polymerization by Scanning Tunneling Microscope Allows Ultrahigh Density Data Storage

Researchers L.P. Ma, S.S. Xie, and S.J. Pang at the Chinese Academy of Sciences and W.J. Yang at Beijing University have developed a technique for ultrahigh density data storage in which they use a scanning tunneling microscope (STM) to produce polymerization in 3-phenyl-1-ureidonitrile (PUN) by applying a high electric field to realize local polymerization. PUN molecules have a strongly delocalized π-electronic system and contain a nitrile triple bond that may be broken allowing polymerization.

In their experiments, reported in the November 30 issue of *Applied Physics Letters*, 20 nm films of PUN monomer material were deposited on freshly cleaved substrates of highly ordered pyrolytic graphite (HOPG) by vacuum evaporation. Current-voltage characteristics of the films were measured in air using a homemade STM with a Pt/Ir tip. The STM was also used to produce local polymerization under high field conditions.

According to the scientists, the as-deposited PUN film "is monomer structured and in a high resistance state." Applying 3.8 v for 10 ms produces local polymerization in the vertical direction. The local polymerization is accompanied by a dramatic increase in the conductivity of the polymerized spot along the polymeric molecular chain direction, that is, the vertical direction. The high-conductivity "recorded" regions of the sample are as small as 0.8-nm long corresponding to "the size of one structure unit cell of the polymeric material." The narrowest gap between two recorded marks is 1.2 nm. Based upon these dimensions, the authors project a data storage density of 10^{14} bits/cm^2.

The authors also used the STM to remove the PUN film from a previously recorded area by applying a higher voltage for a longer time period (5 V for 20 ms) and scanning the tip at high tunneling current. The STM was then used to scan the bare HOPG substrate. The resulting image displayed no features that could be attributed to the recording process, thus reinforcing the author's claims that the recording process is due to polymerization of the PUN film. No degradation of the Pt/Ir STM tip was observed during any of these processes.

The authors estimate that the percentage of successful "writes" is greater than 95%. They also report that the "STM images of the recorded patterns show no discernible change during scanning for 3 hours" and estimate that this corresponds to more than 2,000 "reads" of the data. □

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