RESEARCH/RESEARCHERS

High Electron Mobilities Achieved with an Organic Field-Effect Transistor Material

In the December 4 issue of *Applied Physics Letters*, researchers J.H. Schön, Ch. Kloc, and B. Batlogg of Bell Laboratories report room-temperature electron mobilities as high as 5.5 cm^2/Vs for an organic field-effect transistor (OFET) based on single crystalline perylene. Perylene, also called *peri*-dinaphthalene, has a formula of $C_{20}H_{12}$; the structure shows four 6-carbon rings surrounding, and sharing a side with, a central cyclohexane ring. This promising material shows both *n*- and *p*-channel activities, with the electron mobility clearly exceeding the hole mobility across the 50–300 K temperature range studied. In previous investigations, OFET materials consistently showed hole mobilities that were higher than electron mobilities.

Single crystals of perylene approximately 1-cm^2 in area and a few micrometers thick were grown from the vapor phase in a stream of flowing hydrogen. Gold source and drain contacts were thermally deposited on the perylene layer, and a dielectric layer of Al_2O_3 was sputtered over the surface. A gold gate electrode was evaporated on top of the structure. Structures fabricated included channel lengths from 25 to 50 μm with channel widths from 500 to 1,500 μm.

Standard FET equations yielded electron mobilities of 5.5 cm^2/Vs and hole mobilities of 0.4 cm^2/Vs, in good accordance with time-of-flight values reported for perylene single crystals. The investigators believe the 5.5 cm^2/Vs value to be the highest room-temperature mobility reported to date for an OFET in either polarity mode.

The temperature-dependence of the mobility for electrons followed a power law across the whole 50–300 K temperature range, with mobility increasing with decreasing temperature. The hole mobility demonstrated similar behavior down to 60 K, at which point the mobility leveled off. The researchers attributed this phenomenon to defects, disordering, or trapping processes.

TIM PALUCKA

Individual Layer Thickness of Sol-Gel-Derived BST Thin Films Directs Film Properties

A team of researchers from the Shanghai Institute of Technical Physics (affiliated with the Chinese Academy of Sciences) and Shandong University has shown that the structure, ferroelectricity, and dielectric properties of sol-gel-derived $Ba_{0.8}Sr_{0.2}TiO_3$ (BST) thin films strongly depend on the individual layer thickness. In the October issue of the *Journal of the American Ceramics Society*, the researchers report that the films prepared with an individual layer thickness of 60 nm showed small equiaxed grains with a cubic structure, no ferroelectricity, and temperature-independent dielectric behavior. In contrast, films prepared with a layer thickness of 8 nm consisted of columnar grains with a tetragonal crystal structure and showed good ferroelectricity as well as two peaks in the dielectric constant-temperature curve. According to the researchers, the individual layer thickness for layer-by-layer homoepitaxy growth of BST films should be <20 nm in the sol-gel processing.

While BST is a promising material for dynamic random access memory (DRAM) and uncooled infrared detector applications due to its high dielectric constant and composition-dependent Curie temperature, sol-gel-derived BST thin films have not produced pronounced ferroelectric hysteresis loops. According to Jun-Hao Chu, director of the National Laboratory of Infrared Physics at the Shanghai Institute of Technical Physics, this failure renders such films unsuitable for infrared detector applications. His team therefore decided to work on controlling the microstructure of sol-gel-derived BST thin films.

As reported in the article, 300-nm films with layer thicknesses of 60, 20, and 8 nm were produced by spin coating at 6000 rpm for 40 s in air from stoichiometric solutions of barium and strontium acetate in acetic acid mixed with titanium butoxide in acetylacetone. The layer thickness was controlled by the concentration of the solution used for spin coating. Each layer was pyrolized at 350°C for 5 min to remove residual organics and crystallized at 750°C for 10 min.

"Our results show that the film with a layer thickness of 60 nm is cubic with equiaxed grains of 30–50 nm size," said Jian-Gong Cheng, who recently received his PhD degree from the Shanghai Institute of Technical Physics. "This is a result of random nucleation in the bulk of each layer during the crystallizing process. But when we reduced the layer thickness to below 20 nm, the nucleation was mostly controlled by the structure of the underlying layer. We could get layer-by-layer homoepitaxial growth, which resulted in large columnar grains." While the film with small equiaxed grains showed poor ferroelectric and dielectric properties, a well-defined hysteresis loop and two peaks in the dielectric constant-temperature curve were observed for the film with large columnar grains.

In the August 14 issue of *Applied Physics Letters*, the group reported that

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the films with an 8 nm layer thickness exhibit a large pyroelectric coefficient between 10°C and 26°C with a maximum value of 4.1×10^{-4} C/m^2 K at 16°C. This result demonstrates that the material is a good candidate for uncooled infrared focal plane array applications.

CORA LIND

Broadband Frequency-Tunable Micromechanical Oscillator Promises to Extend the Applicability of Microelectromechanical Systems (MEMS)

Scientists at the Cornell Center for Materials Research have developed a technique for varying the frequency of oscillations over a 300% range in micron-scale cantilever beams. These cantilevers, which are used as micromechanical oscillators, serve as the basic component in numerous microelectromechanical systems (MEMS) devices. When the oscillators are limited to operation at either a fixed resonant frequency or over a narrow frequency range, as, according to the researchers, has previously been the case, the applicability of these devices is restricted. Systems such as electromechanical filters, micromechanical spectrum analyzers, and magnetic resonance force microscopes (MFRM) may benefit from the researchers' work on broadband tunable microresonators.

As reported in the November 13 issue of *Applied Physics Letters*, M. Zalalutdinov, B. Ilic, D. Czaplewski, and co-workers employed a scanning tunneling microscope (STM) as a vibration actuator and a scanning electron microscope (SEM) as a motion detector in order to excite and detect oscillations in low-stress silicon nitride cantilevers (200 μm × 20 μm × 0.6 μm). By applying a small ac voltage to a *z*-piezodrive, the tungsten STM tip, while in contact with the cantilever, was driven with <0.1 nm amplitude in the direction perpendicular to the surface, thus causing it to behave as a point-like actuator. The resulting cantilever motion was detected by scanning the SEM electron beam across the cantilever edge and analyzing the secondary electron yield or video signal. By linearly scanning the electron beam over a distance greater than the motion of the cantilever edge, the resonant frequency of the cantilever oscillations was determined from the position of the peak in the resulting spectrum of the video signal.

Using the SEM, the resonant frequency was measured as a function of the STM tip distance from the cantilever end. The researchers report a continuously variable threefold increase in the resonant frequency as the STM was displaced toward the middle of the cantilever. The cantilever's deflection profile at a fixed tip position was also measured using the SEM. In both cases, the researchers found agreement between the experimental data and predictions obtained using the cantilever beam displacement equation.

"This method allows us to vary the cantilever over such a large frequency. Tunable micromechanical oscillators," said Zalalutdinov, "will provide the basis for the realization of solutions for diverse MEMS applications."

STEFFEN K. KALDOR

High-*Q* Microcavity Based on Whispering Gallery Modes Constructed from Microsphere-Core-Shell Quantum Dot Structure

A group of researchers at the University of Oregon in Eugene proposed and developed a quantum dot microcavity with extremely high *Q* factors. They achieved two important parameters: small effective mode volume and long photon lifetime.

As reported in the November 1 issue of *Optics Letters*, the quantum dot microcavity was achieved by coupling core-shell CdSe-ZnS nanocrystals obtained by organometallic synthesis, with fused-silica microspheres (diameter ~20 μm to a few hundred microns) obtained by fusing a fiber tip with a CO_2 laser. The CdSe-ZnS nanocrystals used have a near-unity quantum yield at room temperature and a narrow linewidth—as determined by photoluminescence measurements (PL) on single quantum dots. To attach the nanocrystals to the fused-silica microsphere surface, the nanocrystals were suspended in a chloroform solution. After taking PL measurements of the composite nanocrystal-microsphere system, free spectral range of the whispering-gallery modes (WGM) of the microcavity was determined to be 0.7 nm for the 100-μm diameter of the sphere. Using a resonant light-scattering technique, the *Q* factor was found to change its value from 1.6×10^6 to 1.6×10^8, corresponding to WGM linewidths of 4×10^{-4} nm and 5×10^{-6} nm. The difference in the *Q* values is due to the absorption of nanocrystals coupled with the relevant WGM. Furthermore, in order to increase the accuracy in *Q* measurement, time-domain ringdown spectroscopy was used in two stages, before and after the sphere surface was reheated. Reheating the sphere surface increased the photon storage lifetime from 0.1 μs to 0.3 μs, corresponding to an increase in *Q* from 2.4×10^8 to 7×10^8. The researchers concluded that the limiting factor in increasing *Q* in the composite nanocrystal-microsphere system is the surface absorption on chloroform.

The research team anticipates that an even higher dipole coupling rate can be achieved using spheres with smaller diameters. According to the researchers, the extreme sensitivity of WGMs to the effects of single nanocrystals should open up a new avenue for probing dynamics, decoherence, and individual quantum transitions in a single quantum dot.

IULIA C. MUNTELE

Microprobing Silicon Surfaces Reveals Low-Resistance Surface Reconstructions

An international team of scientists from the Technical University of Denmark and the School of Science of the University of Tokyo in Japan has discovered that using micro-four-point probes to measure the surface conductivity of structure results in a resistance of two orders of magnitude lower than that for Si(111)-$\sqrt{3}\times\sqrt{3}$-Ag clean surfaces. The researchers attribute this difference to direct transport through surface states, an effect that cannot be observed with the conventional macroscopic four-point probes. Clean facets of many crystalline materials exhibit reconstructions of the outer atomic layers, which result in a new two-dimensional band structure at the surface. Although the dispersion of these bands can be measured by spectroscopic techniques, the characterization of charge transport in these surface states still remains a challenge.

As reported in the December 4 issue of *Applied Physics Letters*, the micro-four-point probes were prepared using silicon-based microfabrication technologies, following a procedure similar to that for atomic force microscope probes. The probes consist of four sharpened silicon oxide cantilevers coated with titanium, extending from a silicon chip. Electrode spacings of 8 and 20 μm were produced and used in these experiments. Once produced, the microscopic probes were integrated into a customized ultrahigh vacuum scanning electron microscope system, and manipulated with microslides for making contact with the analysis samples. The samples were 20×3 mm^2 *n*-type Si(111), with a nominal resistivity of 10–100 Ωcm. The sample surfaces were patterned with laser etching, in order to generate large step-free terraces, and then heated resistively at 1250°C in intervals of 10–60 s for a total of 3000 s. The two surface reconstructions investigated—the Si(111)-7×7 and Si(111)-$\sqrt{3}\times\sqrt{3}$-Ag—

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