# Spectroscopy Focus

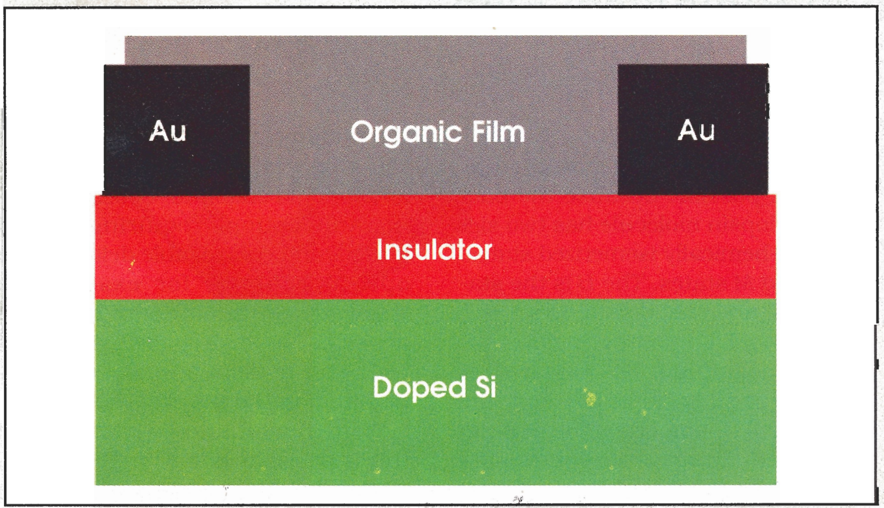
## IR Spectroscopic Techniques Probe Organic Field Effect Transistors

Researchers at the University of California, San Diego, in La Jolla, the University of California, Santa Barbara, and Lawrence Berkeley National Laboratory in Berkeley, Calif., have employed Fourier transform infrared (FTIR) spectroscopy and synchrotron FTIR spectromicroscopy to study organic field effect transistors. Their findings indicate that the techniques are well suited for exploring the intrinsic properties of charge carriers in the devices.

Despite interest in the devices for applications from chemical and biological sensors to flexible displays, the electronic processes in organic field effect transistors are not well understood, said Zhiqiang Li, a graduate student in the physics department at the San Diego campus. A particular challenge is finding noncontact means of investigating the charges in the channel region.

Li noted that the structure of field effect transistors makes it difficult to experimentally study injected charge carriers using some of the most informative techniques in the toolbox of physicists and chemists, such as scanning tunneling microscopy, photoemission spectroscopy, and inelastic x-ray and neutron scattering. The carriers are confined to a nanometer-thick layer at the semiconductor/insulator interface that is buried under several layers of the device. Experimental investigations thus have tended to involve DC transport probes.

*The organic field effect transistors were grid-electrode devices with dimensions of 10 × 14 mm.*



*Fourier transform infrared (FTIR) spectroscopy and synchrotron FTIR spectromicroscopy were employed to investigate charge injection in bottom-contact field effect transistors based on poly(3-hexylthiophene), illustrated here in cross section. Two types of gate insulators were used: a 200-nm-thick layer of $SiO_2$ and a bilayer of 6 nm of $SiO_2$ and 180 nm of $TiO_2$. Images courtesy of Zhiqiang Li.*

In contrast, he said, FTIR spectroscopy is a noncontact, nondestructive method that is well suited for investigating the mechanism of the electronic transport and the nature of voltage-induced electronic states in the field effect transistors. When mobile electrons or holes in organic materials are displaced under the influence of a DC electric field, he explained, they drag the local "polarization cloud" of the molecular chains with them, forming polarons that can be probed spectroscopically.

Spectromicroscopy further enables the interrogation of charges in the conducting channel with high spatial resolution. The technique relies on the intrinsic brightness of the radiation produced by a synchrotron — in the case of Lawrence Berkeley's Advanced Light Source, used in the investigators' work, it is on the order of 200 times brighter at 10 µm than conventional IR sources. The high brightness enables the beam to be focused with little loss to diffraction-limited spot sizes on the order of 2 to 10 µm.

In their research, the scientists studied 10 × 14-mm bottom-contact field effect transistors based on the semiconducting polymer poly(3-hexylthiophene). The devices featured V-shaped electrodes and a gate insulator layer of either 200 nm of $SiO_2$ or 6 nm of $SiO_2$ and 180 nm of $TiO_2$. They employed an FTIR spectrometer from Bruker Optics Inc. of Billerica, Mass., in the spectroscopic studies and a Nicolet microscope and FTIR spectrometer from Thermo Electron Corp. of Waltham, Mass., for spectromicroscopy.

They found that the field effect transistors with the $SiO_2$ insulator displayed no change in the injected charge carrier density in the entire conducting channel with lengths of several millimeters, consistent with the behavior of an ideal device. Those with the high dielectric constant $SiO_2/TiO_2$ bilayer, in contrast, displayed a rapidly decaying carrier density.

The experiments, Li said, indicate that FTIR spectroscopy and spectromicroscopy offer researchers unique tools to explore organic field effect transistors. IR spectromicroscopy's ability to evaluate the quality of gate insulators in the devices may play a role in the search for high dielectric constant insulators to replace $SiO_2$ in metal-oxide semiconductor field effect transistor architectures.

The research team hopes to employ the techniques in the study of other materials in the devices, he said, including polymers, organic molecular crystals and transition-metal oxides. □

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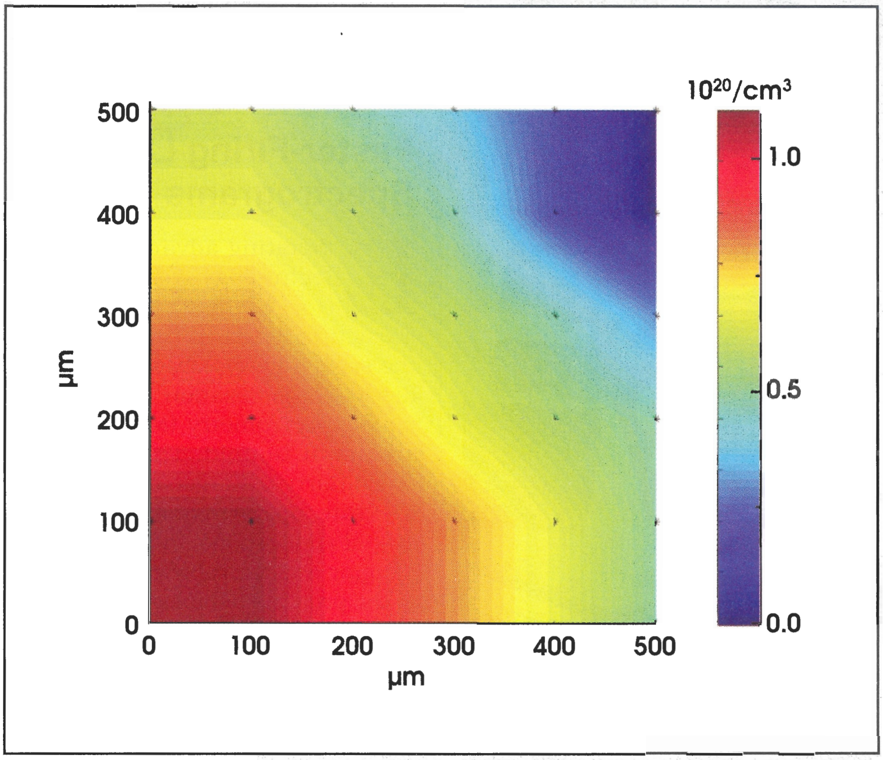

*The decay of the charge carrier density with distance from the electrodes was imaged using infrared beam lines from the Advanced Light Source synchrotron at Lawrence Berkeley National Laboratory.*

# Spectroscopy Improves Nanotube Growth

Better displays may be on the way, thanks to work on carbon nanotube growth by researchers at Kyung Hee University in Seoul, South Korea. Using optical emission spectroscopy, the scientists have found the optimum conditions for the growth of vertically aligned nanotubes in a plasma-enhanced chemical vapor deposition system.

Carbon nanotubes could form the basis of long-lasting, high-performance miniature field emission devices that could be used to create the flat equivalent of the standard cathode-ray tube. To do that, the tubes must be vertically aligned, and the best method to do this has been unclear.

The investigators have determined that the abundance of the CH radical is critical in achieving this alignment. The radicals supply carbon to the growing surface and reduce network etching, explained Kyu Chang Park, a professor in the department of information display.

The scientists sputtered nanotube-precursor nickel catalysts onto a substrate, patterning them via photolithography into 5-µm-diameter disks. They used a mixture of $C_2H_2$ and $NH_3$ at a pressure of a few torr, less than 0.01 atmos, for the plasma. They kept the substrate electrode voltage at −600 V while they tried from −300 to +300 V for the mesh electrode, which sat one-third of the way between the substrate and the grounded top electrode.

To characterize what was going on in the plasma, they set up a Horiba Jobin Yvon spectroscope to view the plasma through a shielded viewport. According to Park, optical emission spectroscopy is the easiest means of analyzing the chemical reactions in the system.

Based on the spectral fingerprints of the dominant CN, H, $C_2$ and CH peaks, the researchers found the +300-V mesh bias to be the best. This setting had the highest emission intensity, possibly because of the dissociation of $C_2H_2$ and $NH_3$ with the increased ion flux. Even higher mesh voltages should help nanotube growth, but Park said that this could not be verified in their setup.

Scanning electron microscope images revealed that the straightest and, therefore, the most defect-free