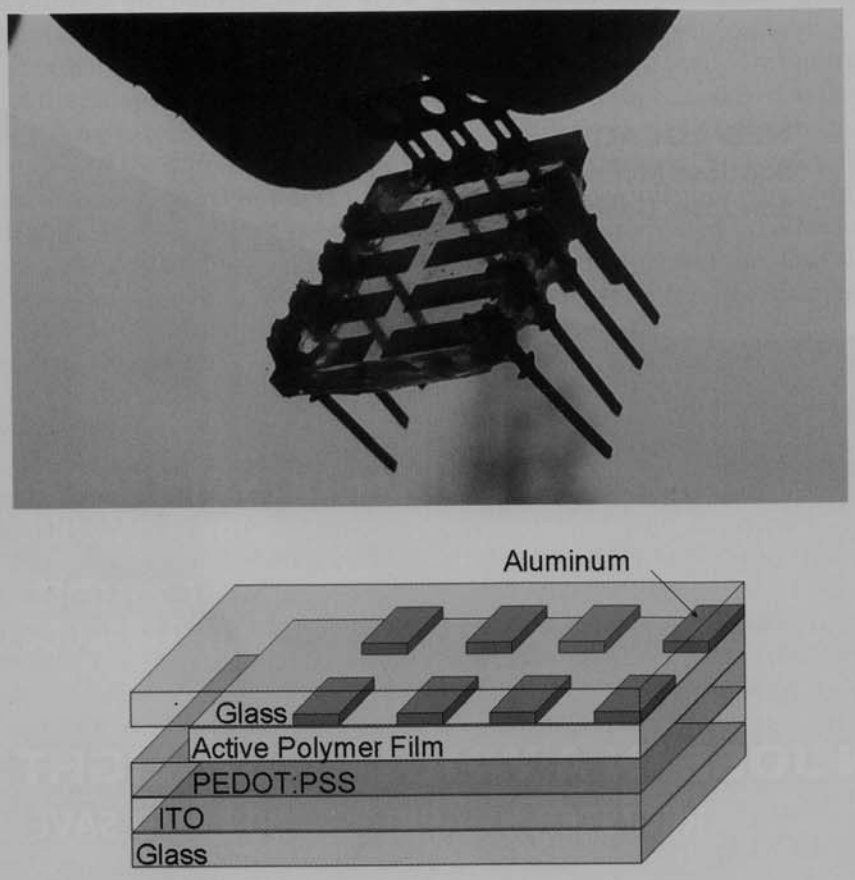
active samples were characterized again within four weeks after the x-ray exposure.

They found that polymers did not degrade significantly after large doses of radiation — equivalent to the lifetime doses used in medical x-ray imaging. "Before this study was carried out, there was a concern that such semiconductors might degrade when exposed to x-rays, as this is sometimes a problem when similar materials are exposed to UV radiation, such as in sunlight," said James C. Blakesley, another author. "Clearly, it is important that the polymers do not stop working when they are exposed to clinical x-rays."



Researchers have demonstrated the efficacy of polymer-based photodiodes for digital x-ray imaging. Use of organic materials could contribute to lower production costs of imaging arrays and thus could help to introduce digital x-ray imaging to the clinic. A polymer-based photodiode is shown here. PEDOT:PSS is the most common material in organic electronics and works as the anode of the photodiode; ITO represents the indium tin oxide layer.

In addition, they demonstrated that polymer diodes could detect x-rays when coupled to gadolinium oxysulfide or to other x-ray-to-light-converting materials. "This is an important first step in showing that polymer electronics could be used for this application."

Still, much remains to be done before polymer photodiodes can be implemented clinically for digital x-ray imaging. For example, such photodiodes typically exhibit either a high dark current or a low sensitivity to light — the former resulting in noisy digital images and the latter, in underexposed images. The photodiodes must be optimized to have a low dark current as well as a high sensitivity, to minimize the amount of radiation needed to yield a good image. Then, technology must be developed to fabricate arrays of organic photodiodes and to integrate them with the transistor arrays that enable digital readout.

The researchers are working toward both of these. They are seeking a way to reduce the dark currents in photodiodes with multilayer structures. Also, they soon will evaluate the performance of a single-pixel detector composed of a polymer photodiode integrated with an organic thin-film transistor.

"This is the basic building block that needs to be multiplied by several million to make a useful imaging array," Blakesley said. □

Gary Boas

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A single optical probe does double duty

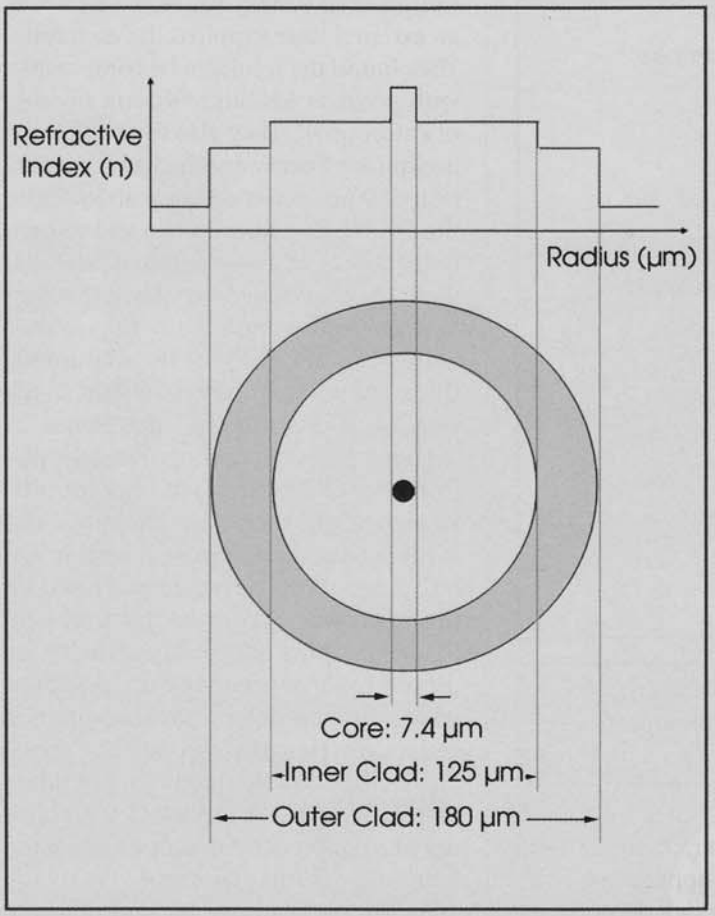
Investigators engaged in fluorescence spectroscopy have had two less-than-perfect choices for fiber optic probes — single- and multifiber. A single-fiber probe has the advantages of a small diameter, a simple configuration and low cost. However, a multifiber probe does not autofluoresce from excitation light as single-fiber types do. This autofluorescence, or background, signal can make it difficult to detect weakly fluorescent samples with a single-fiber probe.

Now a team of researchers from South Korea has demonstrated fluorescence spectroscopy using a single double-clad fiber that yields significant advantages over both types. "This fiber probe provides two independent light channels using only one fiber. Thus, we can achieve the smallest size of a fiber probe," said team leader Byeong Ha Lee.

Lee is a professor in the department of information and communications at Gwangju Institute of Science and Technology in South Korea. Others in the group were from the institute and from Honam University, also in Gwangju.

A single-fiber probe uses an optical fiber — an inner core that is surrounded by a cladding with a lower refractive index. Light enters the core and travels down it as a result of total internal reflection. When a single-fiber probe is used for fluorescence spectroscopy, excitation light passes through the core and strikes the sample. The resulting fluorescence signal traverses the core in the opposite direction and is detected.

The problem is that the excitation light



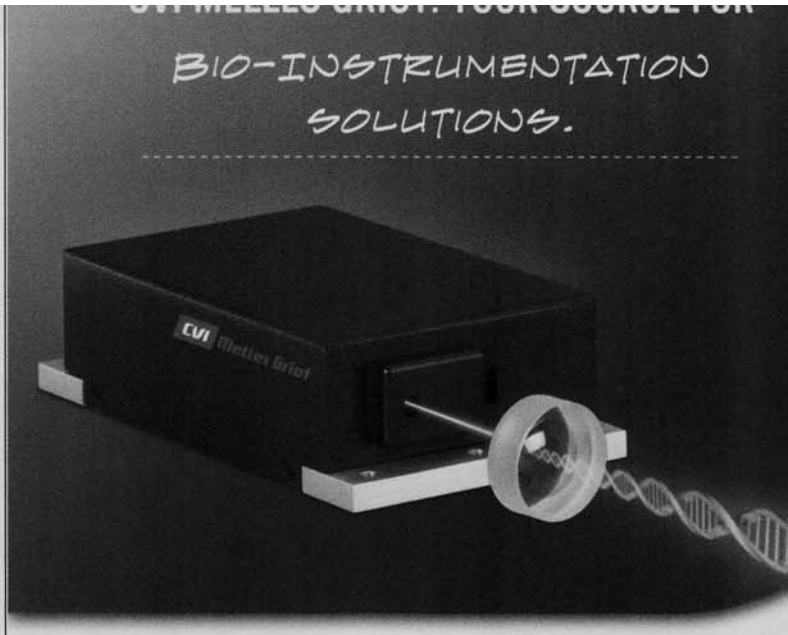
Researchers made a double-clad fiber that works well for fluorescence spectroscopy. This is a cross section of the double-clad fiber, with the top showing the refractive index profile. Excitation light travels down the inner core while the fluorescent signal travels back in the inner cladding. Images courtesy of Byeong Ha Lee, Gwangju Institute of Science and Technology.

causes the core itself to fluoresce, and this background signal can drown out the one from the sample. To solve this, researchers turned to multifiber probes, with one optical fiber delivering the excitation light while others collect the fluorescence. However, multifiber probes' cost, complexity and bulk have been deterrents.

The group took a different approach, turning to double-clad optical fibers, which have a central core surrounded by one cladding that is, in turn, encased in another. If the refractive index of the inner cladding is lower than that of the core but higher than that of the outer cladding, the inner cladding can act as a lightguide much as the core does.

Most commercially available double-clad fibers are designed and intended for fiber lasers, which have different needs and therefore use fibers with different specifications than those for spectroscopic work.

The researchers used a double-clad fiber made with a low-index polymer. They drew the preform of a conventional single-mode fiber in their fiber-drawing tower, substituting a low-index polymer from Luvantix of Gyeonggido, South Korea, for the high-index coating generally used. Lee noted that low-index glass could have been used instead. "We chose the low-index



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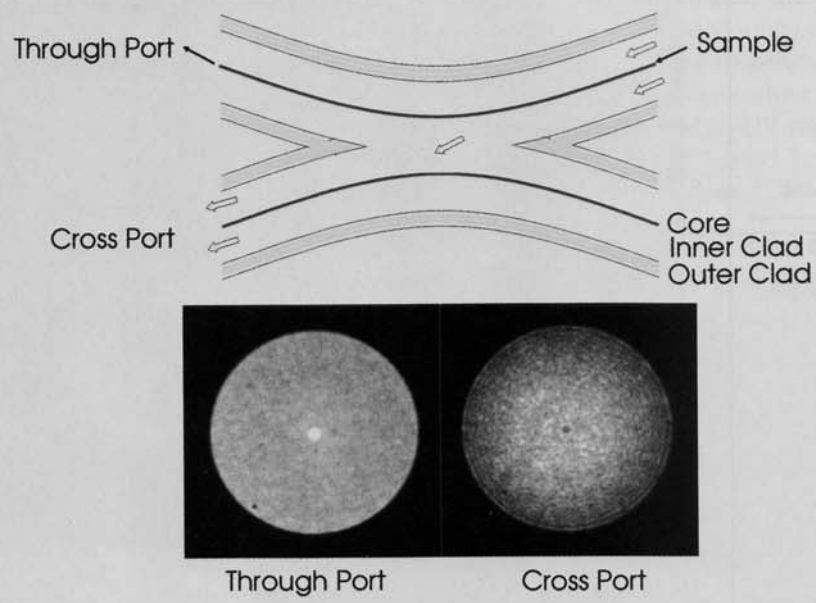

The researchers also designed a coupler that can be used to route the fluorescent signal without disturbing the excitation light. The bottom images are mode-field images from the coupler.

polymer because it could be coated by using our fiber drawing tower, with a minor modification."

He said that other attempts have been made to separate the excitation from the emission channel using double-clad photonic crystal fibers. This approach, though, has required bulk optics and beamsplitters, resulting in a large, bulky setup.

The researchers designed and built a double-clad fiber coupler that allowed them to retrieve light exclusively from the inner cladding of the fiber. Lee said that designing and fabricating the coupler was not a simple affair. They affixed a double-clad fiber to a silica block, side-polishing everything and mating it to another similarly polished double-clad fiber in a silica block. Light traveled down the core of the two fibers without change, but light in the cladding was coupled from one to the other. He added that, although there are no plans to commercialize the overall system the group developed, commercial availability of the coupler itself might be supported through a company.

With the double-clad fiber and coupler, the researchers set up an optical system for fluorescence spectroscopy. They used a Spectra-Physics argon-ion laser, generating a 488-nm beam that went into the 7.4-μm-diameter core of the double-clad fiber.

The fluorescence traveled back via the 125-μm-diameter inner cladding, with the signal routed to the appropriate point by the double-clad coupler. By placing a long-pass filter before the detector, the researchers blocked the reflected excitation light, and they measured the fluorescence signal with an Ocean Optics spectrometer.

They then tested the device by constructing a double-clad fiber probe system and measuring gingko leaves with it, Lee said. They compared these results to those obtained with a conventional multimode fiber system and with one where an external laser supplied the excitation. They found the results to be comparable, with peaks at 685 and 740 nm because of chlorophyll. They also found that the multimode fiber system had a strong peak near 500 nm that was largely absent from the double-clad fiber system and was entirely absent when an external laser was used. They concluded that the feature near 500 nm was the result of autofluorescence within the silica core of the multimode fiber. The research was published in the Dec. 24, 2007, issue of *Optics Express*.

Future plans call for improving the performance of the dual-clad fiber coupler. In theory, the maximum coupling ratio is 50 percent. In the experiment, it was only 15 percent. A change to a fused tapering method of construction may help that ratio. Other improvements being explored involve removing the polymer, which can have significant absorption at certain wavelengths, through the use of an all-silica double-clad fiber. Lee noted that such a fiber complicates the building of a coupler and that optimizing the fabrication is still ongoing.

As for applications, he said that one possibility is an endoscope based on a double-clad fiber probe. "This probe has great potential in disease diagnosis of internal organs with small size, such as the ovary." □

Hank Hogan

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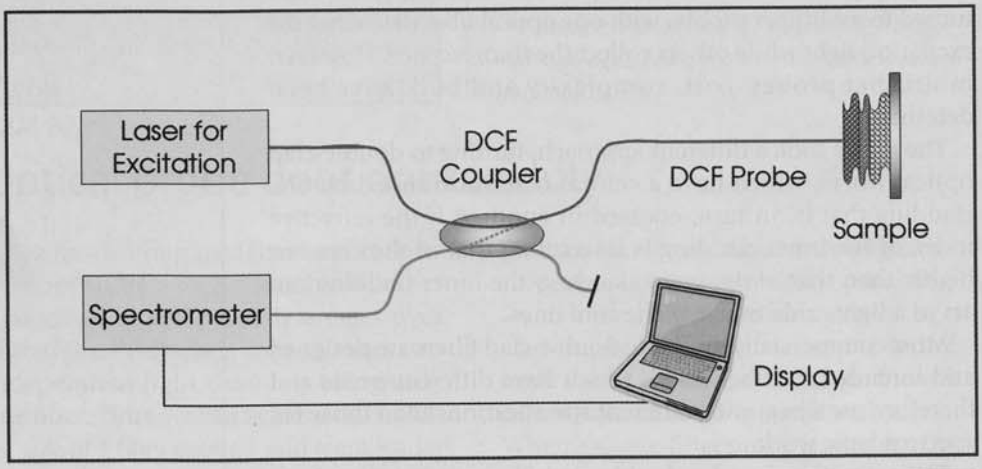

In the experimental setup for spectroscopy using the double-clad fiber (DCF), excitation light from the laser travels down the fiber core while the fluorescent signal travels back in the inner cladding until it reaches a coupler, which routes it to a spectrometer. In the case of the multimode fiber, both excitation and emission travel down the core.