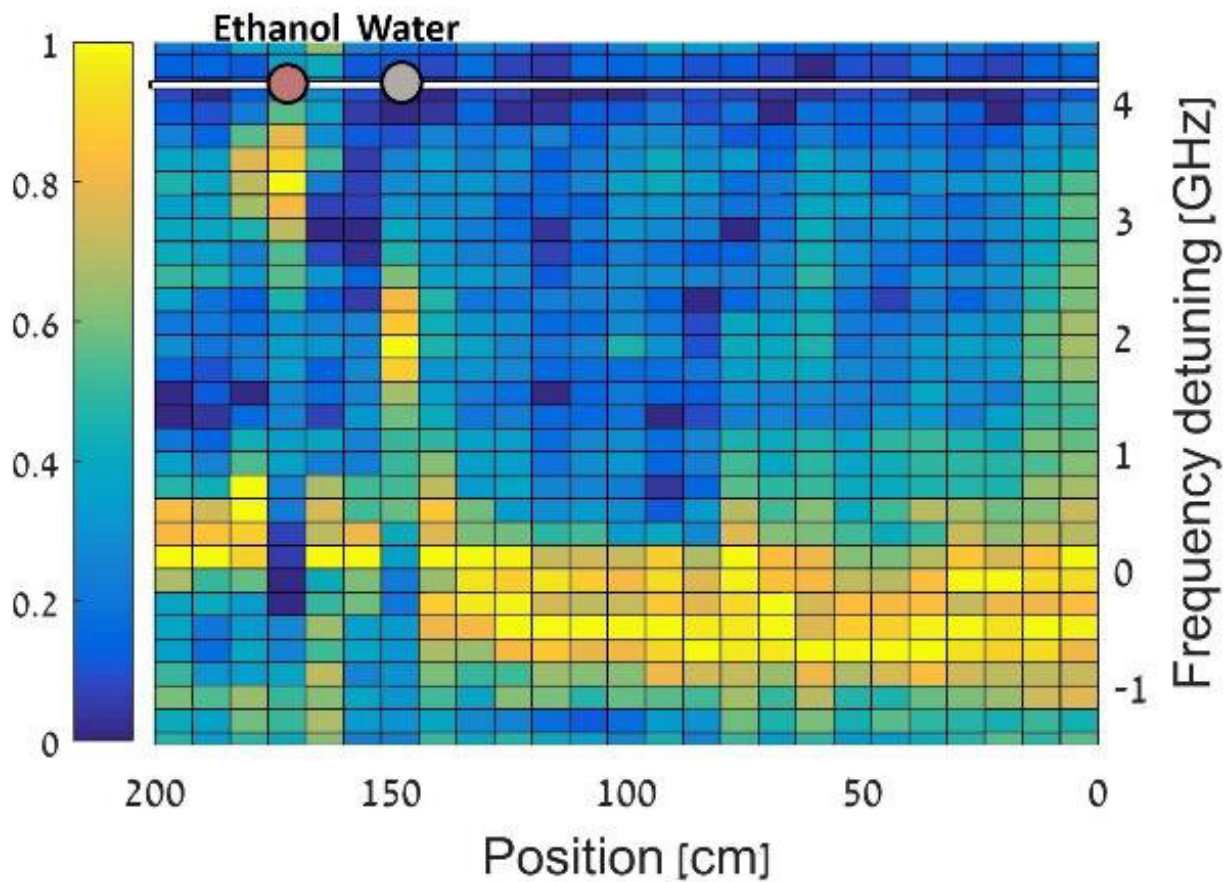


Looking outside the fiber: Researchers demonstrate new concept of optical fiber sensors

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Researchers at Bar-Ilan University in Israel have demonstrated a new concept of optical fiber sensors that addresses a decades-long challenge: the distributed mapping of refractive index outside the cladding of standard fiber, where light does not reach. The sensor can be used for leak detection in critical

infrastructure, and process monitoring in the petrochemical industry, desalination plants, food and beverage production and more. In this image: Distributed mapping of media outside the cladding along two meters of standard optical fiber. Two short segments immersed in water and ethanol are clearly identified by the local spectra of coupling to a cladding mode of the fiber. Credit: Prof. Avinoam Zadok

Optical fibers enable our era of the internet, as they carry vast amounts of data all around the world. Fibers are also an excellent sensor platform. They can reach over hundreds of kilometers, simply embedded within structures, and can be installed in hazardous environment where the use of electricity is prohibited. However, optical fiber sensors also face an inherent, fundamental challenge.

"Everything the light touches is our kingdom," says doctoral student Hagai Diamandi from the Faculty of Engineering at Bar-Ilan University in Israel. "In that, we mean to say that any optical measurement mandates that light should touch the medium under test." Standard optical fibers, however, are designed to do the exact opposite. "Standard fibers are made of a glass [cladding](#), with a much thinner, [inner core](#)," continues Diamandi. "Light is guided at the inner core, and every effort is made to keep light from leaking outside. A substance under test, in most cases, lies outside the much larger cladding. Unfortunately, guided light does not touch upon much of the outside world."

A possible solution is available based on other forms of propagation in the same fiber. Doctoral student Yosef London explains: "In addition to the core mode, light can propagate in the fiber by filling out the entire cladding. In that case, it may 'feel' what's outside." But how do you get light to switch from the 'normal' core mode to those cladding modes? London continues: "Here there's a catch. Coupling to the cladding modes

requires the inscription of permanent, periodic perturbations in the fiber medium, called 'gratings'. Gratings are written at specific, discrete locations. You cannot erase them or move them about." For that reason, cladding mode [sensors](#) are limited to point-measurements only.

The main strength of [optical fiber](#) sensors is spatially-distributed analysis, in which every fiber segment serves as an independent measurement node. Cladding modes could not support distributed measurements, until now. The breakthrough idea came from a third doctoral student in the group, Gil Bashan: "There is an alternative to the use of gratings. We can launch two strong optical waves into the fiber instead. When their frequencies are chosen correctly, the two waves can drive acoustic oscillations within the core of the fiber, at very high hypersonic frequencies. Those acoustic waves become our gratings." The principle is known as Brillouin dynamic gratings. Unlike permanent inscription, Brillouin dynamic gratings can be switched on and off at will. They can also be confined to short segments of arbitrary locations, and scanned along the fiber. "The principle has been used between core modes of fibers for over a decade," says Bashan. "We carry it over to the cladding modes."

In a paper published recently in *Optica* journal, the group reports a distributed cladding mode fiber sensor, a first of its kind. In doing so, they had to overcome considerable obstacles. Advisor Prof. Avi Zadok explains: "There is large disparity in size between core and cladding modes. Core modes are confined to a very tight region. Cladding modes spread over an area 200 times larger. For that reason, we were concerned that the coupling between the two modes would be weak and inefficient." Nevertheless, the team could show the precise measurement of refractive index outside the cladding boundary of standard, unmodified optical fiber. The spatial resolution of the measurements was eight centimeters. The analysis correctly identified short fiber sections immersed in water and ethanol, and clearly distinguished between the

two. The uncertainty in index measurements was in the fourth decimal point.

Prof. Zadok concludes: "We have demonstrated a new concept of [optical fiber sensors](#). It addresses a decades-long challenge: the distributed mapping of refractive index outside the cladding of standard fiber, where [light](#) does not reach." The sensor can be used for leak detection in critical infrastructure, and process monitoring in the petrochemical industry, desalination plants, food and beverage production and more.

More information: Gil Bashan et al, Distributed cladding mode fiber-optic sensor, *Optica* (2019). [DOI: 10.1364/OPTICA.377610](https://doi.org/10.1364/OPTICA.377610)

Provided by Bar-Ilan University

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