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A new spectrometer for planetary exploration

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A novel liquid crystal waveguide architecture enables electro-optic Fourier transform spectrometers on a chip scale.

The potency of Fourier transform spectroscopy (FTS) for chemical analysis is well established.[1] It provides identification and quantification of multiple biogenically important compounds such as CH_4, NH_4, NO_x, and H_2O with a level of sensitivity in the parts per million range and the specificity inherent in spectroscopic analysis. FTS is built upon the technique of interferometry, in which a beam of light from an emitting source is split (usually with a semitransparent mirror assembly) and the resulting beams are made to travel over differing distances, creating a time delay. The beams are then recombined, and the resulting interference pattern is used to characterize properties of the light and, by inference, the source. In a Fourier transform spectrometer, the mirror assembly of a traditional Michelson interferometer is movable, allowing patterns to be measured over several time delay settings. However, the use of FTS sensors on planetary rovers and other remote missions has been complicated by the optomechanical requirements for scanning. The moving mirror assembly presents size, weight, power, and durability design challenges. For this reason, there has been a long-standing effort to replace the moving mirror with an electro-optic (EO) element where the tunable optical path difference (OPD) between the two arms of the interferometer is scanned by electronically controlling the speed of light. While an FTS that employs this method is obviously attractive, previous efforts at developing a usable system have been hindered by the lack of an EO technology that provides sufficient path difference tunability.[2] In order to replace the mechanics in an FTS, the system must provide tunability over millimeters or even centimeters of OPD, several orders of magnitude larger than has historically been possible.

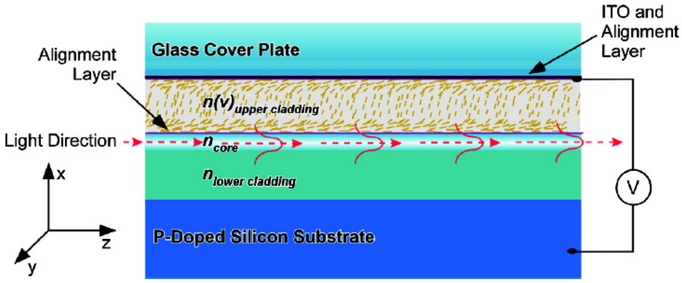

Figure 1. *A side view of a liquid crystal (LC) waveguide. By voltage tuning the index of the LC upper cladding, we can voltage-tune the total waveguide index. ITO: Indium tin oxide.*

To address this challenge, Vescent Photonics in collaboration with NASA's Jet Propulsion Laboratory (JPL) has been developing a new EO waveguide architecture that provides unprecedented voltage control over the optical path difference. Tunability above 1mm has been demonstrated, with the potential to achieve 1cm or greater. This increased level of control has already made possible new devices with remarkable performance attributes, including ultrawide fields of view (80°), nonmechanical laser beam steerers, chip-scale lasers with nearly 40nm tunability, and ultra-low-power ($<5\mu W$) tunable microring filters and Mach–Zehnder switches.[3–5] All of these devices can be housed in small LCD-like packages that can ultimately be as low cost as a calculator display. In the current Vescent-JPL collaboration, we are exploiting this architecture to build a new generation of EO-FTS systems.

The key to building an EO architecture that realizes millimeter-scale OPD is to use liquid crystals (LCs), the most electro-optic materials known at present, in a new architecture that circumvents historic limitations. Specifically, we use the crystal as an active cladding layer in a waveguide geometry where the light skims along the surface of the LC layer (see Figure 1). This electroevanescent architecture has several advantages over previous designs. The light never crosses a transparent electrode and only interacts with the well-behaved LC-surface layer via the evanescent field. As a result, the interaction length is now decoupled from the LC layer thickness.

In one example of an LC-waveguide interferometer, a near-IR laser ($\lambda = 1.44\mu m$) is coupled into the waveguide (see Figure 2).

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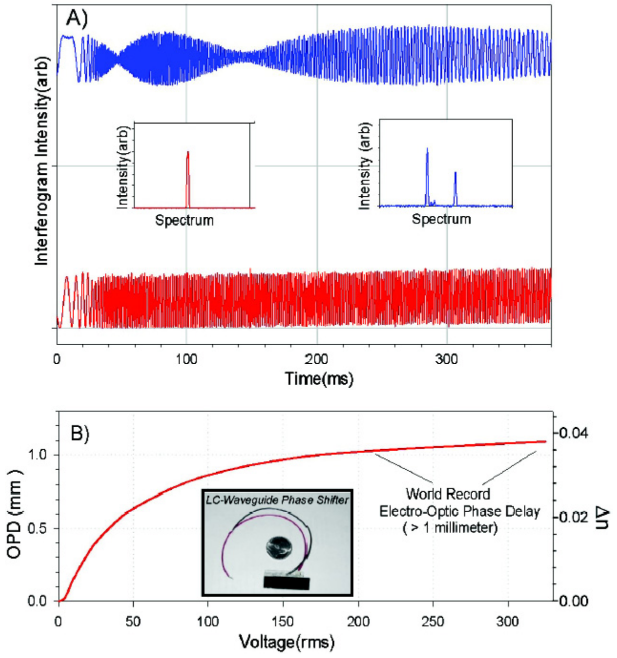

Figure 2. *(A) An LC waveguide Fourier transform interferogram. The upper trace shows the interferogram of a multimode diode laser. The lower trace shows that of a pure wavelength source. The 'beat note' for the multimode laser is clearly visible in the top trace. (B) The tunable optical path difference versus applied voltage. The inset shows a picture of the device (next to a nickel for scale). arb: Arbitrary units. OPD: Optical path difference.*

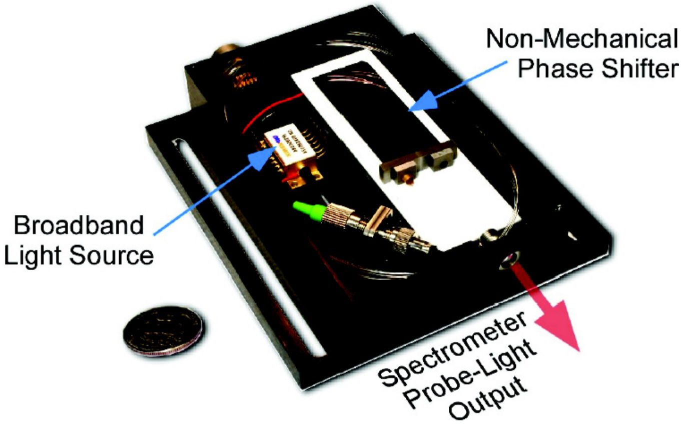

Figure 3. *An LC waveguide Fourier transform spectrometer (FTS) prototype. Not depicted are the 45° tilted polarizer and the detector onto which the probe light is pointed. The coin is shown for size comparison.*

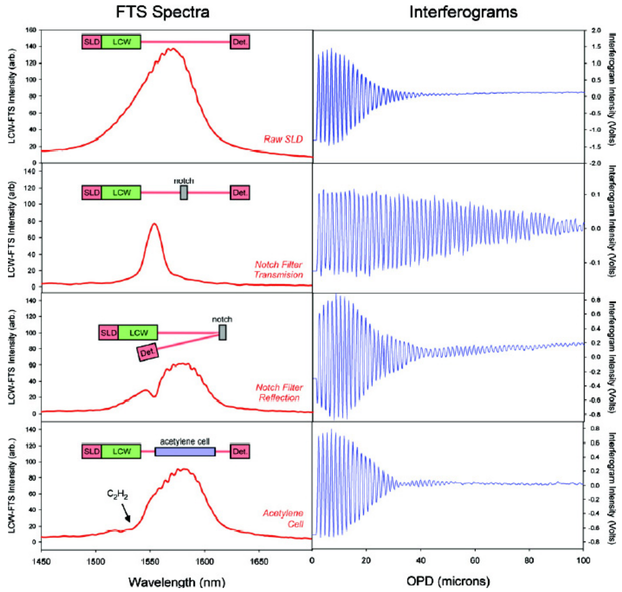

Figure 4. *The interferogram from a broadband light source along with the spectra for a variety of absorption features, including reflection from and transmission through a spectral notch filter, and transmission through an acetylene cell. LCW: Liquid crystal waveguide. SLD: Superluminescent diode. Det.: Detector.*

Each time the OPD of the interferometer is varied by one-half of an optical wavelength, the output light goes from a maximum to a minimum. This device exhibited nearly 1000 waves, greater than 1mm of voltage-driven tunability.

With this level of performance one may now envision chemical sensors based on miniaturized, robust, and nonmechanical FTSs. Such sensors may be deployed for either in situ or remote chemical and spectral analysis. The potential advantages of an LC-waveguide FTS sensor are small size (comparable to a book of matches), a mass of only tens of grams, low energy consumption, the capability to detect chemical densities less than 10^{13} molecules per cubic centimeter, and robust monolithic construction.

While this envisioned sensor is still in development, a prototype LC-waveguide FTS sensor has been built (see Figure 3). The prototype spectrometer provides a near-IR spectral range from about 1450 to 1700nm, and a spectral resolution of 5nm (see Figure 4). The integrated broadband light source is a superluminescent diode. The system is designed for in situ analysis, though both remote and reflectance systems are possible. Ongoing engineering of the system should improve the resolution to 0.5nm and possibly even 0.1nm, ultimately providing the small, low-power, and nonmechanical package envisioned.

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Scott R. Davis is a co-founder and vice president of technology of Vescent Photonics. He is developing a range of LC-waveguide-based devices, including tunable ring resonators, LC-waveguide Fourier transform IR spectrometers (FTIRs), LC-waveguide polarization modulators, and wide-angle beam steerers. He received his PhD from JILA at the University of Colorado, Boulder. He has presented numerous papers at SPIE conferences.

George Farca is a staff scientist. He is involved in LC-waveguide design and fabrication for a range of applications, including LC-waveguide FTIRs, beam steerers, and wavelength-selective tunable switches. He received his PhD from Oklahoma State University, Stillwater.

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