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# Electro-optic steering of a laser beam

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*A liquid-crystal waveguide offers unprecedented voltage control over optical phase.*

Numerous applications, such as bar-code scanners, laser rangefinders, and topology mapping, require controllably altering the direction of a laser beam. Typically, this is done by mechanically moving a mirror or lens where the laser can be focused and deflected. This process can impose significant limitations on many important performance criteria of both the optical devices and the mechanical instruments used to move them. These include cost, size, weight, vibration immunity, power consumption, speed, and device lifetime. People have therefore long sought an electro-optic (EO) scanner, that is, a device capable of changing a laser's propagation angle with a lens (or another optical component) that can be altered electronically.

The most desirable EO scanners are those that provide high-speed operation and a wide range of steering angles (field of view). In addition, they are compact, simple, and low cost.[1–5] Until recently, the only alternatives to mechanically controlling lenses or mirrors relied on a diffractive approach to change the beam's direction. These methods used a diffraction grating (an optical component with a periodic structure that splits light into several beams) or another similar device to change the laser's direction.[2,5–9] Since the grating efficiency drops as scan angle increases, these techniques have typically been limited to small-angle scanners.

Rather than continue down this well-trodden 'diffractive' path, we have taken a new approach. Our EO scanners work by refracting (bending) light, where the deflection can be controllably altered through a voltage change. When a beam of light travels through a piece of glass (such as a lens or a prism), its propagation direction is changed by refraction. The amount of bending depends on the index of refraction of the material. By electronically changing this index, we can use three electrodes to voltage tune the propagation angle at which the laser beam exits the device. This means that we can steer light without any moving parts.[10] Our method provides a simple and cost-effective way of electro-optically controlling a beam's direction, focus, and delay. Figure 1 shows an example EO scanner with a $40° \times 10°$ field of view. A circular, 1550nm beam enters the device through one of the angled facets, and an EO scannable beam exits through the other facet.

The enabling innovation is to use liquid crystals (LC)—that have by far the largest electro-optic response of any known material (e.g., at least $10^5$ times larger than that of lithium niobate)—in a new configuration. Rather than transmit through an LC cell, which by design must be thin (typically less than $20\mu$m-thick), we use the crystals as a cladding layer in an 'LC-waveguide' architecture (see lower panel of Figure 2). The evanescent field of the guided wave extends into an adjustable-index LC cladding. This selectively employs the well-ordered LC-surface region that provides low scattering losses (less than 0.5dB/cm) and fast response times (in the range of 10 to $500\mu$s). Furthermore, the interaction length is now decoupled from the thickness of the LC layer. This allows us to circumvent the

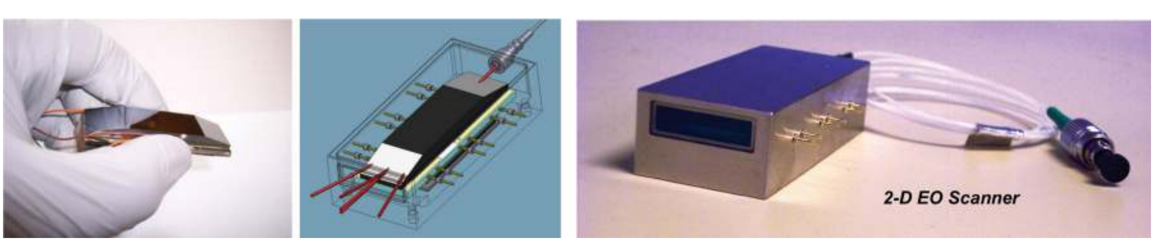


*Figure 1. Wide-field-of-view electro-optic (EO) scanners. (left) The EO element. (center) The photonics package around the EO element, and (right) a packaged scanner.*

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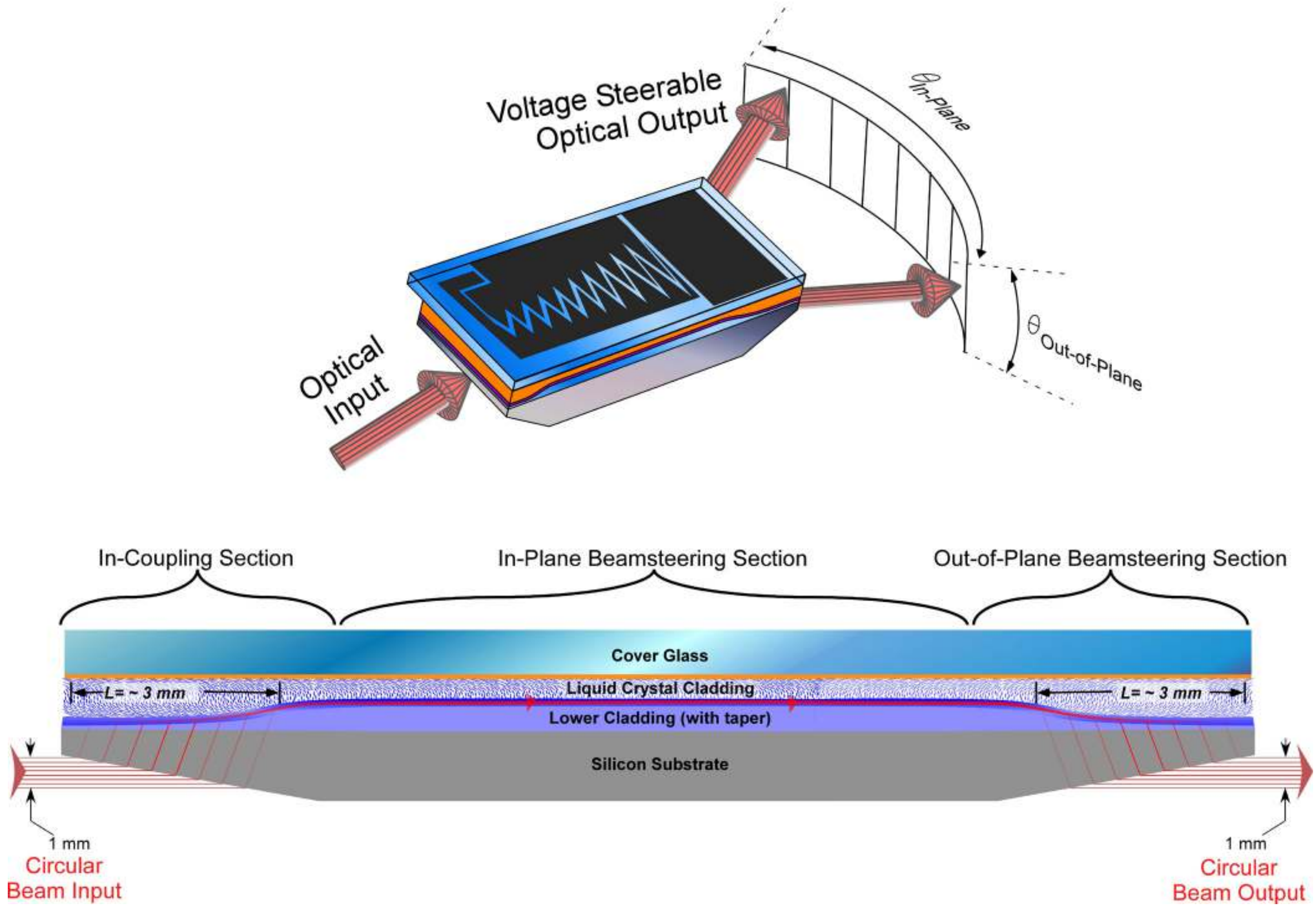


***Figure 2.*** *(top) A 2D electro-optic laser scanner. Voltage applied to the zigzag-patterned electrode provides in-plane scanning, and voltage applied to the rectangular one yields out-of-plane scanning. (bottom) A side view of a liquid-crystal-waveguide scanner that provides a means for getting the light into and out of the device and out-of-plane scanning control.*

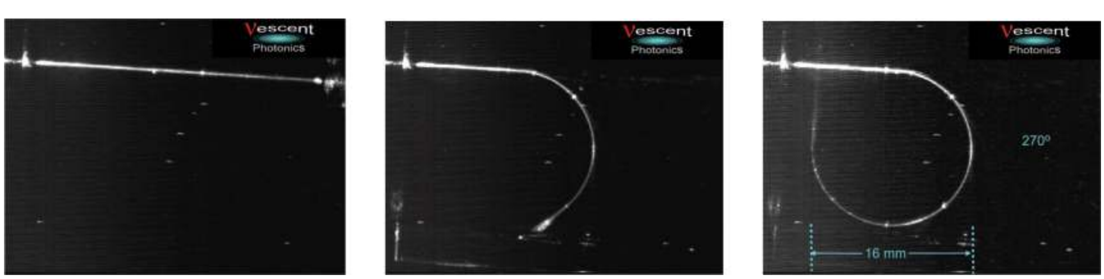


***Figure 3.*** *Example data from an electrode pattern that provided steering of 1550nm light by 270° in a package smaller than the size of a US dime.*

historic LC-limitations of a short interaction length and slow relaxation times.

To the extent of our knowledge, we realize substantially larger voltage control over optical phase (greater than 2mm) than any other approach. With this level of command, we can easily steer the laser beam non-mechanically. For scanning in the plane of the waveguide, we pattern an electrode into refractive shapes (see Figure 2). Voltage applied to the electrodes tunes the index inside these regions, thereby providing a tunable Snell's law of refraction. To realize scan control out of the plane of the

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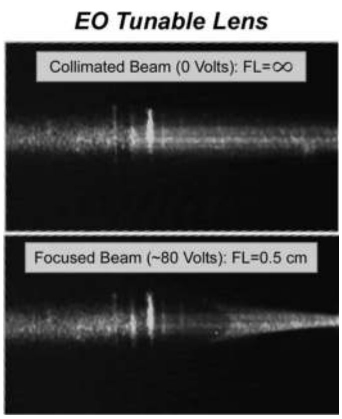


***Figure 4.*** *Operation of a voltage-tunable lens. FL: Focal length.*

waveguide, we use integrated prism couplers.[11] Voltage tuning the LC-waveguide index of refraction in the out-coupler region controllably alters the out-of-plane scan angle. The steering is non-diffractive and analog. A short video of a 2D scanner in operation is available.[12]

To show the large EO control over optical beams of our technique, we recently demonstrated in-plane beam steering of 270° in a package smaller than the size of a US dime (see Figure 3 and second part of video[12]). The images show the scattered streak of light as it propagates through the device. We also demonstrated that the refractive shapes can be curved, resulting in voltage-tunable lenses. Figure 4 shows the operation of an example lens that provides continuous voltage tuning of the focal length from infinity to 0.5 centimeters. The upper panel shows a collimated beam at zero volts and the bottom image shows a voltage-controlled focused beam.

The LC-waveguide construction is a new electro-optic architecture that provides unprecedented voltage control over optical phase. This design realizes wide-field-of-view laser scanners, voltage-tunable lenses, and other formerly mechanical functionalities. In the future, we will continue to improve the performance of our devices by increasing the beam size, scan angle, and scan speed. We will also test packaged EO scanners for use in unmanned aerial vehicles and other environmentally demanding applications.

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Scott Davis is developing a range of liquid-crystal-waveguide-based devices including tunable ring-resonators, Fourier transform infrared spectrometers, tunable lasers, and wide-angle beam steerers. Prior to joining Vescent, Davis served as a National Research Council postdoc at the National Institute of Standards and Technology in Gaithersburg, MD, and obtained his Ph.D. from JILA, University of Colorado.

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