New Wide Angle Electro-Optic Laser Scanners Enable Optical Sensors on Previously Inaccessible Platforms

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Abstract: The world has long sought an electro-optic (EO) alternative to mechanically moving lenses and/or mirrors. Opto-mechanics can impose significant limitations on many important performance criteria including: cost, size, weight, vibration immunity, power consumption, speed, and device lifetime. To help alleviate this we have developed a new EO architecture that provides simple and cost effective electro-optic control over a beams direction, focus, and/or delay. For example, in this paper we present an EO laser scanner with a $40^{o}\times10^{o}$ field of regard. The output angle may be voltage set to any value within this field of regard with only three control electrodes. These scanners, and other devices enabled by our new EO architecture, have very low power consumption, are small, fast, rugged, and simple to use.
OCIS codes: 000.0000; 130.0130; 120.0120

1. Introduction

EO scanners that provide high-speed, wide field-of-views (FOVs), are compact, simple, and low cost have been a long-standing dream of the optical community.[1-5] Unfortunately, they are still not available. This is not for lack of effort; for example, liquid crystal (LC) based tunable diffraction gratings or "optical phased arrays" have been in development for more than thirty five years.[2, 5-7] Other diffractive approaches such as MEMs arrays (though these are still inherently mechanical),[8] electro-wetting arrays,[9] and acousto-optics have also been explored. Typically, these diffractive approaches have been limited to small angle scanners because the grating efficiency drops as scan angle increases. Rather than continue down this well trodden "diffractive-path" we have taken a new approach. We exploit a new EO architecture that provides unprecedented voltage control over optical phase, which enables previously unrealizable *refractive* scanners.[10]

2. The Enabling Innovation: Giant Voltage Control Over Optical Phase

The enabling innovation is to utilize liquid crystals (LCs), which have by far the largest electro-optic response of any known material (e.g., $>10^5$ times larger than lithium niobate), in a new configuration. Rather than transmit through an LC cell, which by design must be thin (typically < 20 μm), we utilize the LC as a cladding layer in an "LC-waveguide" architecture, as shown in Figure 1. The evanescent field of the guided wave extends into an adjustable-index liquid-crystal cladding. This selectively utilizes the well ordered LC-surface region which provides low scattering losses (<0.5 dB/cm) and fast response times (in the range of 10 to 500 μsecs). Furthermore, the interaction length is now decoupled from the thickness of the LC layer. This allows us to circumvent the historic LC-limitations of a short interaction length and slow relaxation times. We realize substantially larger voltage control over optical phase than any other approach that we are aware of; we recently realized greater than 2 mm.

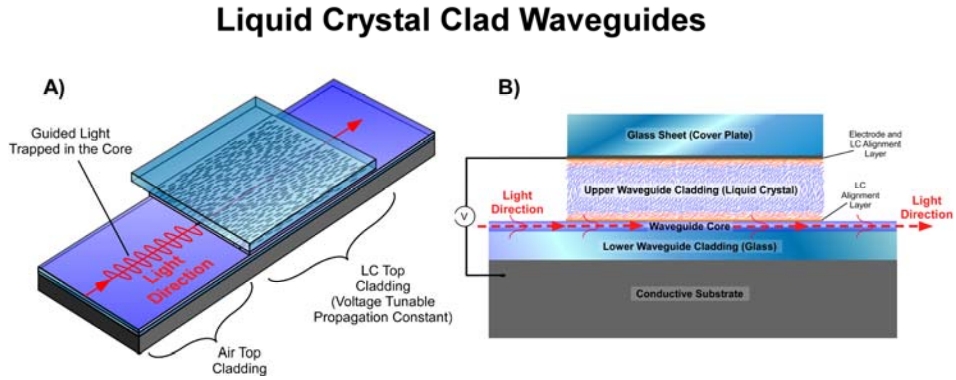

Figure 1 A) The basic geometry of an LC-waveguide. The light is confined to a core and the LC is an electro-optic upper cladding. As the index of refraction of the upper cladding is tuned the "effective index" of the guided mode is also tuned. B) A side view of a liquid crystal waveguide. In a slab waveguide the light is guided in the *x* dimension, but is free to propagate as Gaussian beams, sheets, or even 1D images in the plane.

This giant control over optical phase provides a natural solution to the problem of non-mechanical beam control. For scanning in-the-plane of the waveguide we pattern an electrode into refractive shapes, as shown in the top of Figure 2. Voltage applied to the electrodes tunes the index inside the refractive shapes, thereby providing a tunable Snell's law refraction. To realize scan control out-of-the-plane of the waveguide we utilize integrated prism couplers,[11] as shown in the bottom of Figure 2. 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. New 2-D devices can provide 40^o x 10^o of scan control. Pictures of recent 2-D EO scanners are shown in Figure 3.

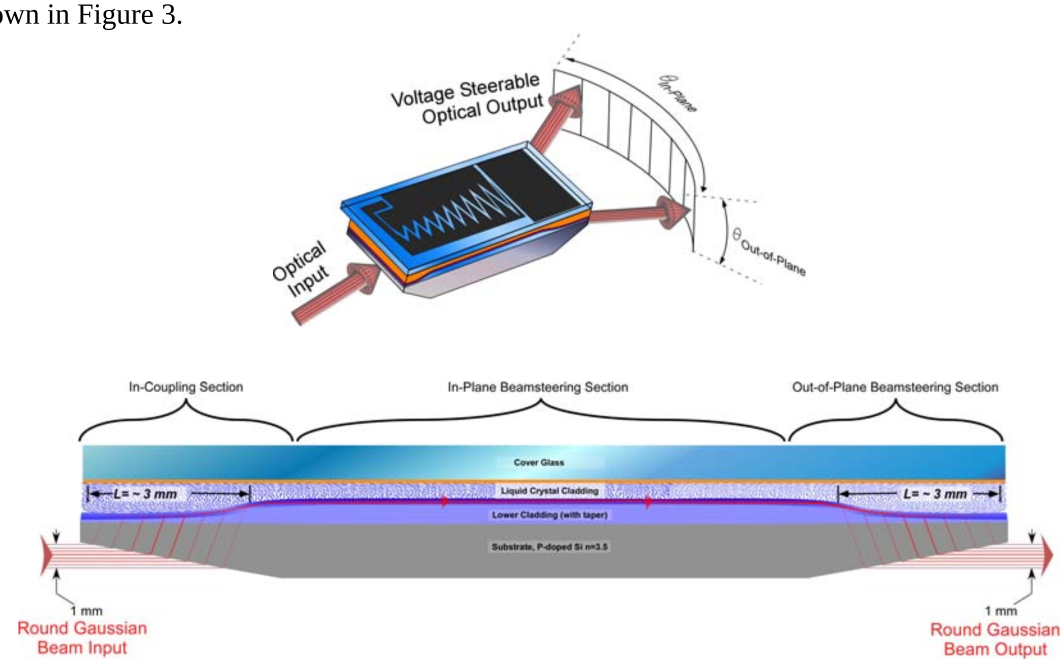

Figure 2 A) A 2-D electro-optic laser scanner. Voltage applied to the zig-zag patterned electrode provides in-plane scanning and voltage applied to the rectangular electrode provide out-of-plane scanning. B) A side view of a liquid crystal waveguide scanner. Integrated tapered-couplers provide both convenient coupling of round Gaussian beams and out-of-plane scanning control.

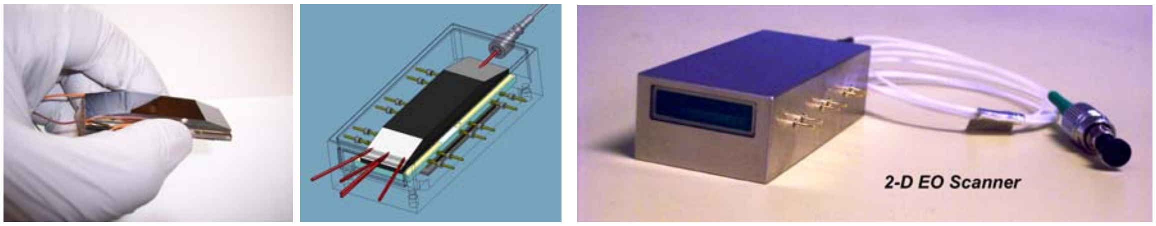

Figure3: Pictures of simple, wide field of view EO scanners. LEFT) The electro-optic element. A circular, 1550 nm beam enters the device through one of the angled facets and an EO scannable beam exits through the other angled facet. MIDDLE) The photonics package around the EO element. RIGHT) A packaged EO scanner.

Since the voltage control over optical phase is so much larger than other technical approaches we can realize dramatically larger EO control over optical beams. By way of example we have recently demonstrated in-plane beam steering of 270^{o} (an unheard of amount for any technology) in a package that is smaller than a dime, as shown in Figure 4.

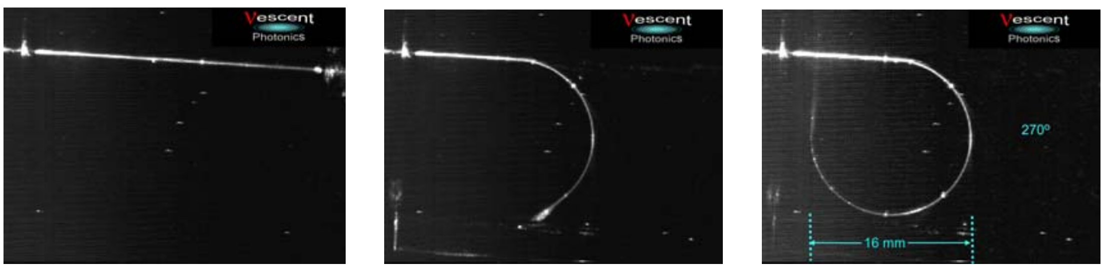

Figure 4: Example data from an electrode pattern that provided steering of 1550 nm light by 270 degrees in a package that is smaller than a dime.

The LC-waveguide architecture is a new electro-optic architecture that provides unprecedented voltage control over optical phase (> 2 mm). This previously unrealizable level of control makes possible new electro-optic alternatives to opto-mechanics. These devices can provide wide field of view laser scanners, voltage tunable lenses, and other formerly mechanical functionalities. Finally they are small, low power, and simple to use. This will enable optical sensing in environments where the restrictions imposed by mechanics are limiting.

4. References

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