Liquid Crystal Polarization Gratings (LCPGs)

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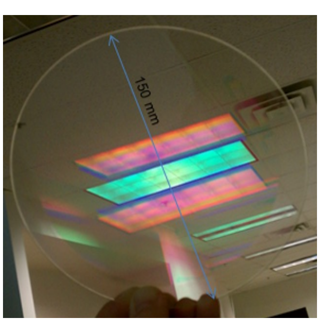
This application note describes the use of Liquid Crystal Polarization Gratings (LCPGs) *in non-mechanical beam steering. This approach has applications in aerospace, automotive, manufacturing & automation, telecommunications, and wind power generation industries.*

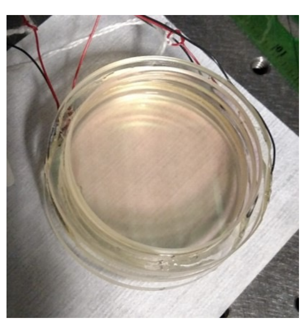
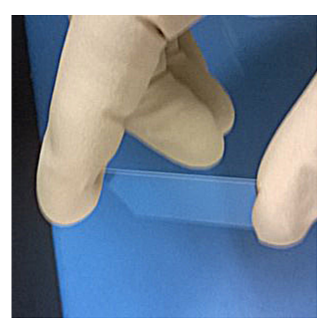
LCPGs are nonmechanically reconfigurable optics with vastly superior size, weight, and power requirements compared to their mechanical counterparts. Meadowlark Optics is the exclusive provider of LCPG non-mechanical beam steering.

Industries Using LCPG Technology

Along with our customers, we have demonstrated this technology in a range of cutting-edge applications, from lidar to optical communications:

- Aerospace: Inertialess optical beam steering with dramatic reductions of size, weight, and power
- Automotive: Wide-angle steering of flash and coherent lidar for ADAS and autonomous vehicles
- Manufacturing + Automation: Increase range and resolution of conventional Time-of-Flight cameras without sacrificing field of view
- Telecommunication: Nonmechanical coarse pointing, acquisition, and tracking, as well as nonmechanical divergence control
- Wind Power Generation: Compact nonmechanical pointing of coherent Doppler lidar wind sensing



Examples left to right: large aperture, doppler lidar, and 200 nm-thick liquid crystal polarization gratings

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LCPG-based Optics for Nonmechanical Beam Scanners

Liquid crystal polarization gratings are also known as geometric phase gratings, Pancharatnam-Berry phase gratings, and diffractive waveplates. These transmissive gratings efficiently (> 99.5%) diffract circularly polarized light to either the first positive or negative order, based on the handedness of the incident light. By incorporating fast electro-optic half-wave polarization retarders to control the handedness of polarization, we can develop custom LCPG devices and systems with a range of leading capabilities:

- Wide-angle beam steering > 100°
- Large apertures > 20 cm
- Sub-millisecond switching times
- Dramatically reduced size, weight, and power (SWaP) requirements
- Random-access and inertia-less beam steering
- Dynamic focusing also available

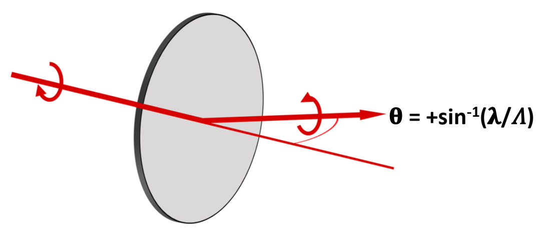

Figure 1: Diffraction of circularly polarized light through an LCPG

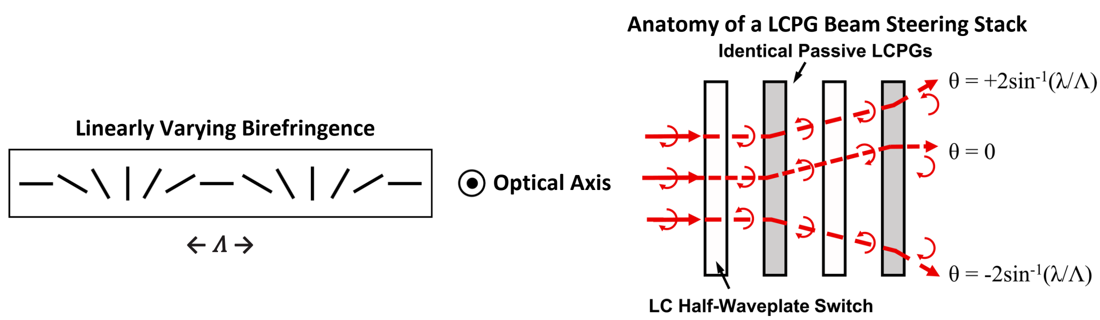

Figure 2: Beam Steering With LCPGs

LCPGs for Nonmechanical Beam Steering and Switchable Optics

Liquid crystal polarization gratings (LCPGs) are diffractive elements that provide near-100% diffraction for circularly polarized light. When layered with thin polarization-controlling liquid crystal elements, LCPGs provide a means of non-mechanically reconfiguring light into different states, such as for beam steering or focusing. Meadowlark Optics owns the patent on this unique beam steering approach (US 8,982,313 B2).

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Coherent Doppler Lidar

Coherent Doppler lidar provides a means of optically sensing an object's range and relative velocity along the line-of-sight (LOS). In one particularly powerful application of this technique, coherent Doppler lidar of aerosols in the air can be used to measure down-range wind speeds. By measuring the wind speeds along multiple widely spaced LOS, the 3D wind vectors for a volume of air can be calculated. Such information is extremely useful in monitoring wind fields near airports, planning wind farms, and even controlling individual wind turbines.

Because 3D wind sensing lidar requires a small number of widely spaced angles, excellent wavefront quality, and is inherently polarization sensitive, the application is very well suited to using LCPG-based nonmechanical beam steering. Conventional 3D wind-sensing lidar systems rely upon motorized optics or multiple telescopes to provide the required LOS. Using LCPGs, a single transmissive window can generate the LOS while reducing the required size, weight, and power (SWaP).

APPLICATIONS: Automotive Sensors, Wind Power Generation

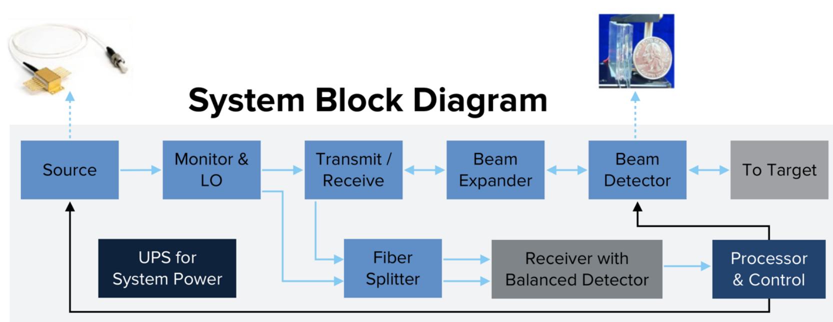

Figure 4: Coherent Doppler Lidar System

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High-Definition Time-of-Flight Imaging

Time-of-flight (TOF) three-dimensional (3D) imaging provides a complementary fit for the LCPG steering technology. TOF cameras and flash lidars use a focal plane array (FPA) to simultaneously detect the return from thousands of locations in the receiver's field of view (FOV). Large FOVs typically require diverging beams and wide-angle optics that reduce the amount of signal collected relative to background noise, and the angular resolution is limited by the resolution of the TOF FPA.

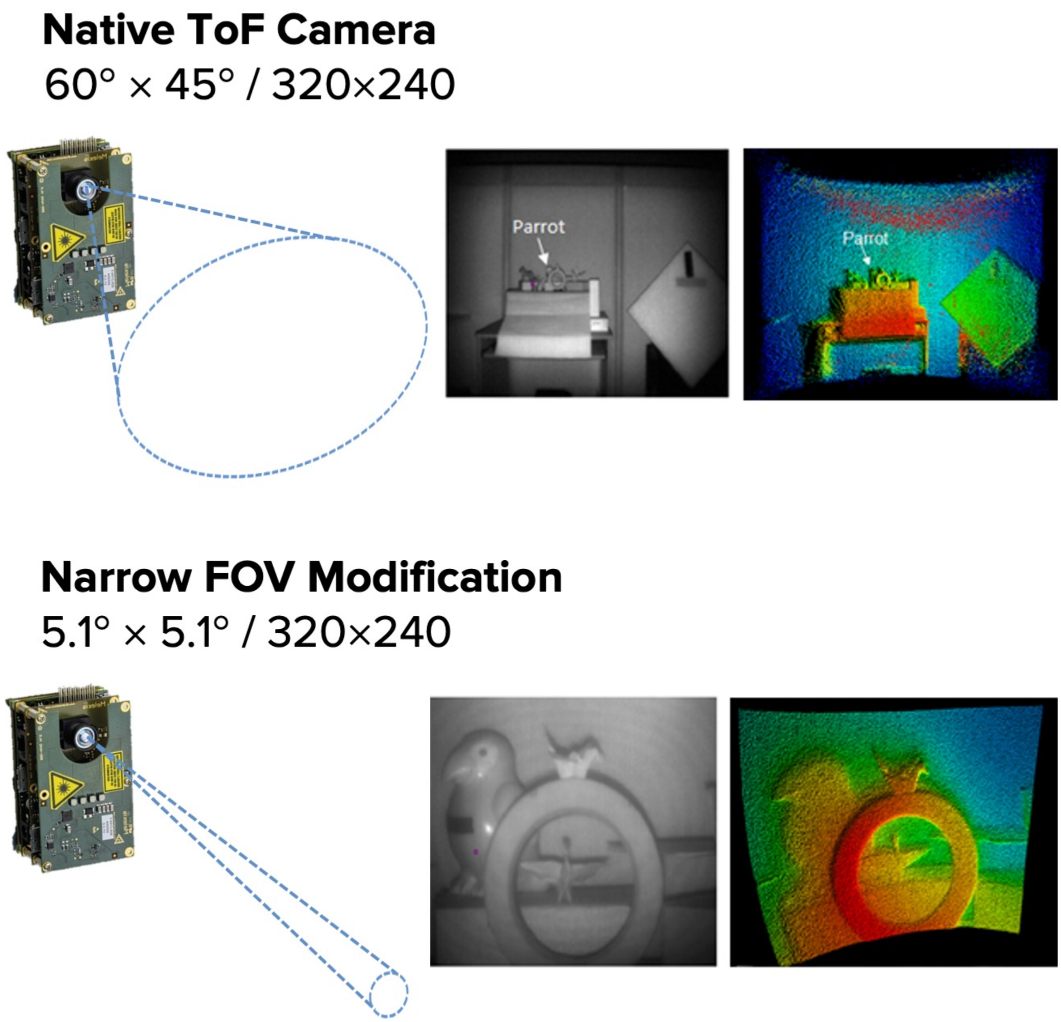

Figure 5: Use of LCPGs with Time of Flight Camera

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Using LCPGs, a TOF camera can concentrate illumination and signal collection over a narrow-angle for high signal-to-noise ratio (SNR) and angular resolution, then non-mechanically scan both transmitter and receiver to regain a large FOV and high effective pixel count. We demonstrated this approach with a commercial TOF camera to boost range and resolution while reducing power consumption.

APPLICATIONS: Automotive Sensors, Manufacturing Inspection and Factory Automation, Aerospace and Defense

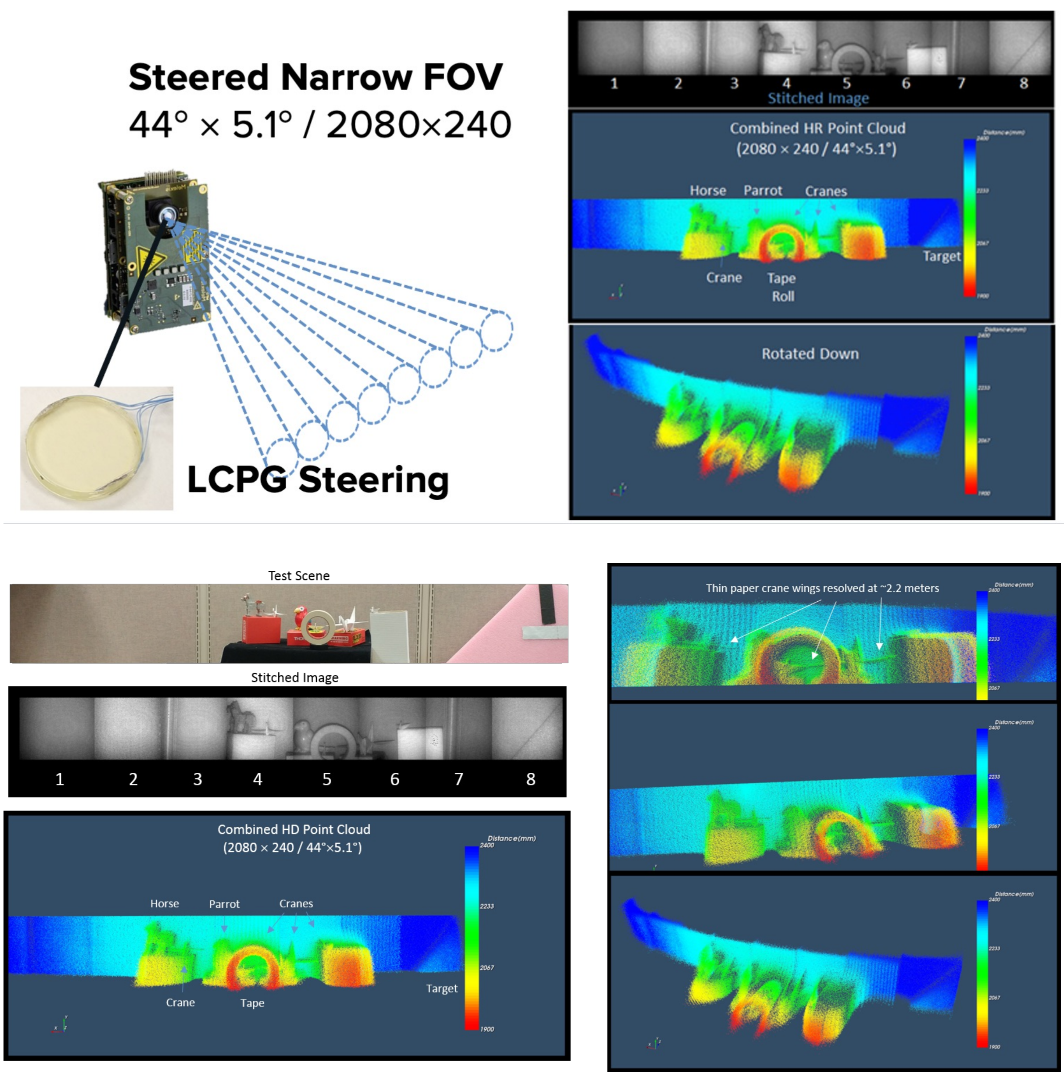

Figure 6: Enhanced ToF range and resolution using LCPGs

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Nonmechanical Refocusing in Microscopy

The brain's neurons are connected in 3D, and that's challenging to study with laser scanning microscopes that natively look at one depth at a time. Existing methods of changing a microscope's focus aren't fast enough to catch neuronal dynamics happening on the millisecond timescale across the millimeter-length scale of neuronal connectivity.

Making things even more challenging, some neuroscience researchers are moving toward low-magnification, large-NA objectives for higher resolution over a larger field of view. Some of these microscope objectives are heavy, so they're slow to mechanically refocus. They also tend to have large back apertures, some in excess of 30 mm in diameter, making them difficult to refocus with technologies such as liquid lenses.

To solve this problem, we took advantage of a technology we'd previously developed for 2D beamsteering and applied it to flexible axial refocusing. Using liquid crystal polarization grating lenses (LCPG lenses) in combination with controllable liquid crystal (LC) switches, we were able to show focus changes of more than 500 micrometers in less than 40 microseconds in a multiphoton microscope.

APPLICATIONS: Photostimulation, Optogenetics, Machine Vision, Remote Focusing

Switching Speed	• 40us fast direction • <3ms slow direction (slow direction can be reserved for recoil)
Focal Plane Change	• >500 µm in combination with a low-magnification objective • Amount of focal plane change is independent of speed
Nonmechanical Steering	• Unaffected by gravity or acceleration • Does not ring or couple vibrations
Aperture	• Large, clear aperture of 100 mm or more • Aperture size does not affect switching speed
Damage Threshold	• Beam is defocused as it enters the lens stack • Pulsed damage threshold is ~1 J/cm2

Table 1: Remote Focusing with Switchable PG Lens Stacks

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