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Liquid-Crystal-Based Optics for use at THz-QCL Frequencies

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Terahertz-frequency (THz) radiation sources and detectors have seen considerable progress in recent years, along with their potential applications. However, development of practical THz systems is hindered by the limited availability of optical components that operate in this frequency range. Several adaptive optical devices have been proposed to modulate the amplitude and phase of THz radiation dynamically. However, few of these operate above 2.5 THz. As such, there remains a need for devices compatible with high bandwidth or narrowband high-frequency THz sources such as quantum-cascade lasers. Liquid crystal (LC) materials are widely used at optical wavelengths, and several have demonstrated birefringence at sub-to-low THz frequencies (< 2 THz). Here, we present the first controllable LC attenuators designed for operation in the 2–4 THz band and demonstrate their potential use in controlling the emission power of a 3.4-THz QCL with modulation depths in excess of 40%.

The devices fabricated for this study were based on an LC material layer enclosed within planar THz transparent cells; a commercially available nematic LC mixture, E7, was selected for this study based on prior measurements of its large birefringence from 0.2–2.0 THz (Δn = 0.13–0.15) [1]. As most materials used in the construction of conventional visible or infrared LCDs have poor transparency at THz frequencies, fused quartz and a conductive polymer (PEDOT:PSS) were chosen for the LC windows and electrode layer respectively, with a long-chain polyimide (SE-3510) layer used to achieve monodomain alignment of the LC molecules.

THz time-domain spectroscopy was used to characterize the materials over a 0.3–8 THz bandwidth [2] at a range of bias voltages, applied across the LC layer as a 5-kHz sinusoid. A birefringence of 0.14–0.18 was determined in the 0.3–4.0-THz range, limited by a phonon at 5 THz in the fused quartz windows.

A linearly polarized, collimated beam from a 3.4-THz QCL [3] was passed through the LC device, orientated so the director was parallel to the polarization direction, and the transmitted power was measured using a helium -cooled bolometer. Modulation depths of up to 40% were seen for a 100 µm LC layer thickness. This modulation was caused by a combination of effects, namely the linear dichroism between the two optical axes of the LC material, and etalon interference between the LC/electrode/quartz interfaces, with the former effect being dominant.

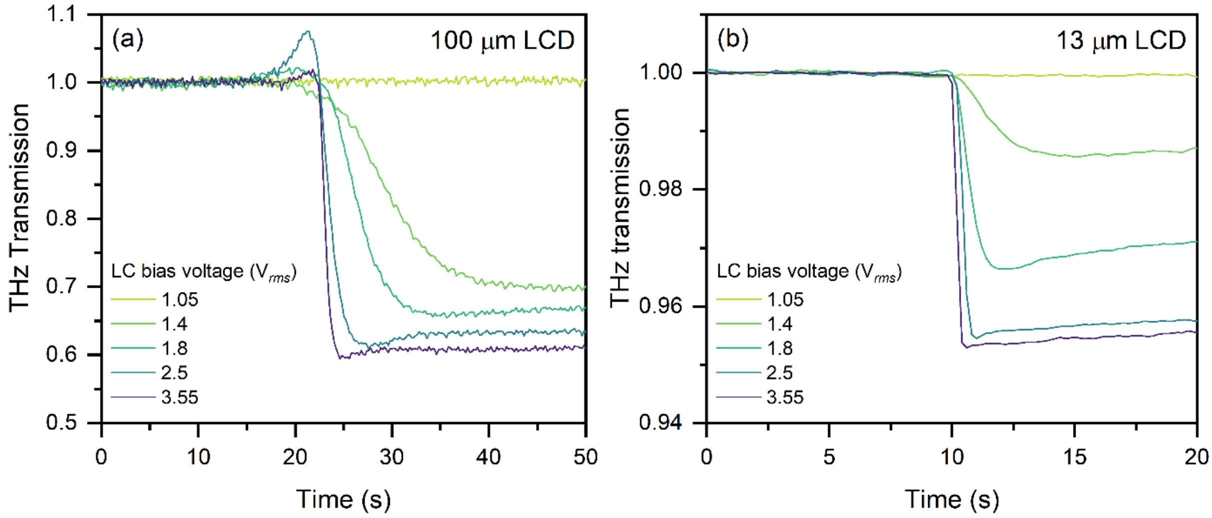

Fig. 1. (a) Transmission of linearly polarised THz radiation from a 3.4-THz QCL through the extraordinary axis of two liquid-crystal devices with nominal thicknesses of (a) 100 µm and (b) 13 µm as a function of the V_{rms} voltage applied.

References

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