

this condition at relatively low magnetic fields. The rotation angle can be set to $\pi/2$ by changing the thickness of the *n*-InSb crystal and fine-tuning magnetic fields.

Finally, we will discuss how the performance of the *n*-InSb polarization optics depends on the material parameters such as the electron density and scattering time. The cold magneto-plasma model, which describes our experimental data very well, provides a guideline for tailoring desired polarization characteristics. For further broadband operation as a circular polarizer, there is a trade-off between the bandwidth and the insertion loss. To achieve ultra-broad bandwidth ($\gg 1$ THz), we need to shorten the scattering time, increase the electron density, or thicken the crystal in an extreme way. However, these lead to a significant increase in the transmission loss of the CRI mode due to the residual absorption from the high-frequency tail of the magneto-plasma resonance at ~ 0.1 THz. For less broadband operation with ~ 1 THz bandwidth, it is easy to achieve very low loss (less than 10% absorption loss) circular polarizer and the center frequency is tunable with the magnetic field. The working frequency range demonstrated here is from 0.3 to 2.5 THz, which is only limited by the THz detection bandwidth, and is already ~ 1.5 times broader than that of the previously reported achromatic quarter-wave plate [15]. The *n*-InSb circular polarizer should work in the higher frequency region except for the Reststrahlen band (5.5-5.9 THz). Both the dispersion around the cyclotron resonance and the absorption loss increase with temperature (T) due to an exponential increase in the number of thermally excited carriers [20]. As illustrated in the theoretical plot in Fig. 5, at elevated temperatures one can achieve similar performance to that in cooled samples by increasing the magnetic field and decreasing the sample thickness. Figure 5 is plotted for $T = 250$ K, the magnetic field $B = 5$ T and a sample of 0.3 mm thickness. The density of thermally excited carriers is calculated to be $3 \times 10^{15} \text{ cm}^{-3}$, which leads to the absorption coefficient around 15 cm^{-1} over the plotted frequency range. The maximum input THz field would be ~ 50 kV/cm since above this field strength impact ionization is expected to produce high carrier densities (on the order of 10^{16} cm^{-3}) [33]. Finally, although the *n*-InSb polarization optics work in a “static” mode with a permanent magnet, a “dynamic” mode is possible with a repetitive pulsed electromagnet [34] to make a fast polarization modulator. Recent advancements in the table-top pulsed electromagnets (peak magnetic fields of around 10 T) will enable us to realize such devices.

6. Conclusion

We observed a giant Faraday effect in *n*-InSb using polarization-resolved THz time-domain spectroscopy. Polarization rotation angles and ellipticities as large as $\pi/2$ and 1, respectively were obtained over a wide range of frequencies and were tunable with the external magnetic field, temperature (electron density), and crystal thickness. The results show its promising ability for constructing broadband and tunable THz polarization optics, such as a circular polarizer, half-wave plate, and polarization modulators.

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