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Time-Domain Terahertz Spectroscopy in Pulsed Magnetic Fields

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Introduction

Magneto-optical measurements in the far infrared range have been of fundamental importance in condensed matter physics. Frequently, such measurements are conducted using time-domain terahertz spectroscopy (TD-THz), which covers the frequency range from 0.1-3 THz. Standard TD-THz entail measurements of ~1s, whereas many interesting phenomena only manifest when subject to the high fields accessible in pulsed magnets, which are generally limited to millisecond duration. The inherent incompatibility of these two timescales has inhibited studies of numerous systems. To surmount this obstacle, we are utilizing advancements in high speed sampling to enable TD-THz measurements in pulsed magnetic fields.

Experimental Results

A commercially available TD-THz system has been delivered from Toptica Photonics, which measures the THz electric field on sub-ms timescales. Data acquired using this system is presented in Fig. 1, where each of the colored traces indicates a distinct measurement of the THz electric field transmitted through an $YFeO_3$ orthoferrite sample during a span of 5ms. Concurrently, we have constructed a 5kJ capacitor bank, which has been used in separate experiments to produce magnetic fields of 35T. Importantly, the experimentally relevant portion of each TD-THz trace is restricted to a small range (indicated by the colored circles in Fig. 1) near the THz E-Field maxima, during which the magnetic field changes very little. Additionally, the discharge of the capacitor bank is timed such that the peak magnetic field (blue curve in Fig. 1) coincides with a measurement of the THz electric field. Thus, we are able to effectively measure the steady state THz transmission during the ~millisecond duration of a pulsed magnetic field. Then, by Fourier transforming each waveform in Fig. 1, we can access the complex transmission ($|T|e^{i\phi}$) of $YFeO_3$ at a series of magnetic fields. The resulting $|T|$ spectra (Fig. 2a) clearly displays an absorption feature, known to be an antiferromagnetic (AF) resonance. The frequency of the AF resonance (f_{AF}) is near 0.5 THz at 0T but systematically shifts to ~0.66 THz at 13.3T. To more clearly resolve the magnetic field dependence of f_{AF}, we simply conducted further THz measurements while varying the pulsed magnetic field amplitudes. f_{AF} was extracted from the additional THz transmission spectra and is plotted in Fig. 2b, as a function of magnetic field. The observed super-linear relationship between f_{AF} and magnetic field is consistent with previous studies, thereby confirming the viability of this new experimental setup.

Conclusions

We have successfully demonstrated the viability of our newly constructed pulsed magnetic field, TD-THz system. This setup will be utilized to access a relevant, but largely unexplored experimental regime, and guide the development of more advanced and higher field capabilities.

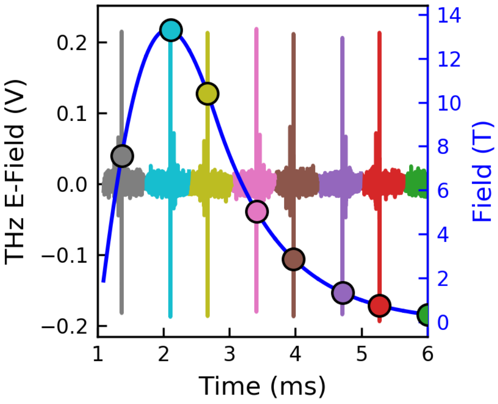

Fig. 1: A series of THz electric fields (colored traces) transmitted through $YFeO_3$ were acquired during the pulse of a small magnet, powered by the 5kJ capacitor bank (blue curve). The magnetic field at which each THz E-field was measured is indicated by the matching colored circles.

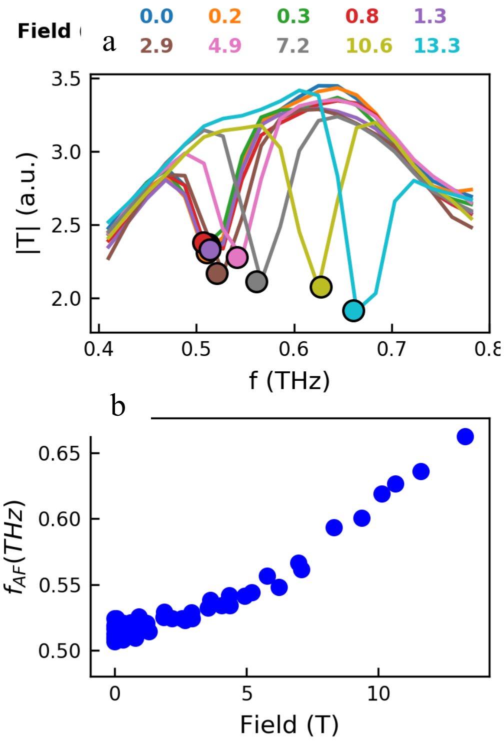

Fig. 2: a) The |T| spectra corresponding to the THz E-fields traces in Fig. 1, of matching color. The circles indicate the location of the AF absorption. b) The resonant frequency of the AF resonance frequency extracted from a series of TD-THz measurements at various fields.