



Direct measurement of cyclotron resonance in a high-temperature superconductor: Ultrafast THz spectroscopy in pulsed magnetic fields



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Funding Grants: G.S. Boebinger (NSF DMR-2128556); S.A. Crooker (DOE "Science of 100T"); I. Božović (DOE BES); N.P. Armitage (NSF DMR-1905519)

The renormalization of effective electronic masses in materials is a well-established consequence of electron-electron (e-e) and electron-lattice interactions. However, precisely *how* this renormalization manifests depends on the measurement. Angle-resolved photoemission, quantum oscillations (e.g., Shubnikov-de Haas) in high magnetic fields (B), and heat capacity all measure masses that reflect the underlying renormalized quasiparticle dispersion. In this regard, cyclotron resonance (CR) merits special consideration, as it provides an especially direct measure of carrier mass via $m_c = eB/\omega_c$, where ω_c is the cyclotron frequency of the charge carriers.

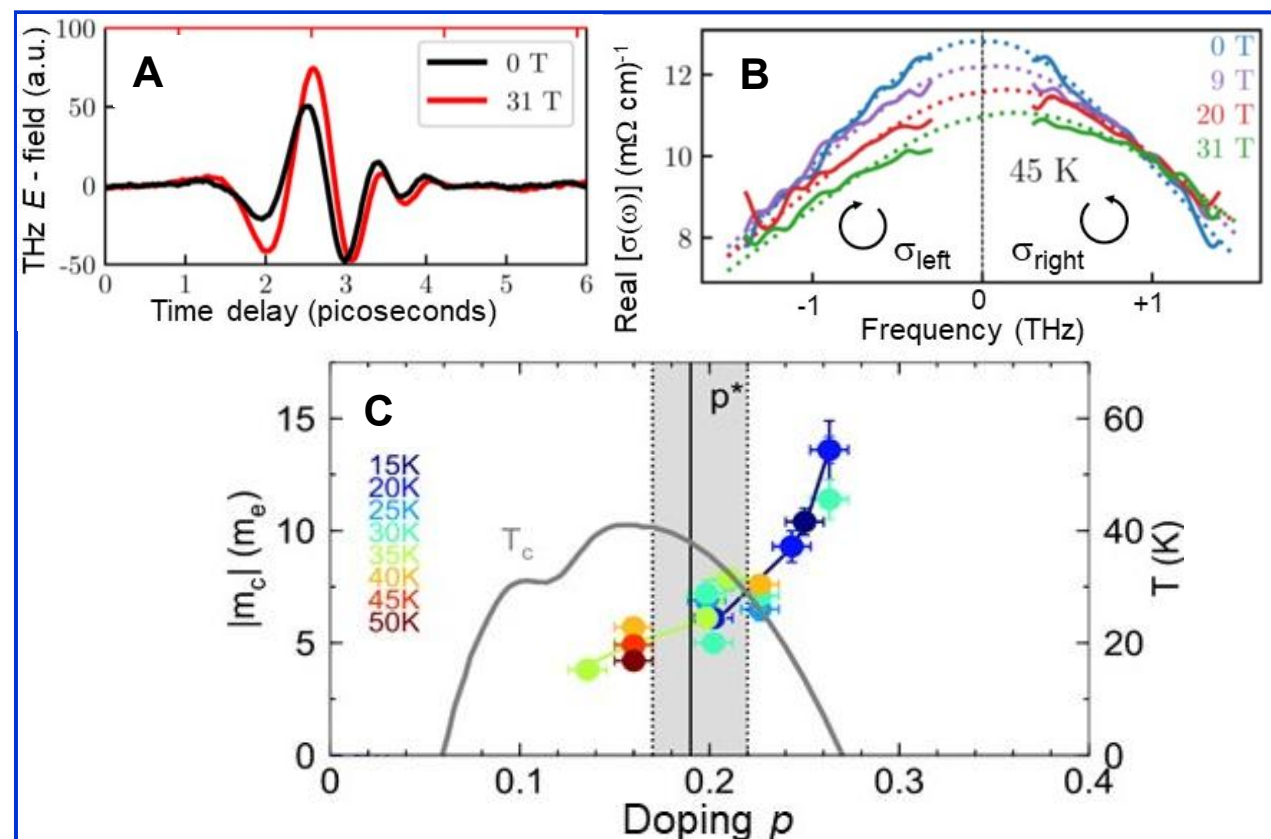
In high- T_c superconducting cuprate (HTSC) materials, CR studies complement other methods; however, due to large masses and scattering rates, very high B and broad (THz) bandwidth is needed. MagLab users coupled a time-domain THz spectrometer to a purpose-built 31T pulsed magnet to measure the broadband THz optical conductivity of $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ (LSCO) thin films that ranged from slightly underdoped to highly overdoped ($p=0.13$ - 0.26). Systematic changes in the circularly-polarized complex conductivity reveal CR of p -type charge carriers (holes) with masses ranging from $m_c \approx 4 - 14m_0$.

Besides providing the first direct measurement of cyclotron mass in a HTSC, these data reveal an unexpected monotonic increase of m_c with doping and a scattering rate that increases with B . These results open the door to characterizing the influence of e-e interactions in cuprate superconductors.

Facilities and instrumentation used: Pulsed 31T free-space optics magnet and time-domain THz spectrometer at the MagLab's Pulsed Field Facility.

Citation: [1] Legros, A.; Post, K.W.; Chauhan, P.; Rickel, D.G.; He, X.; Xu, X.; Shi, X.; Bozovic, I.; Crooker, S.; Armitage, N.P., *Evolution of the cyclotron mass with doping in LaSrCuO*, **Physical Review B** **106**, 195110 (2022) doi.org/10.1103/PhysRevB.106.195110

[2] Post, K.W.; Legros, A.; Rickel, D.G.; Singleton, J.; McDonald, R.; He, X.; Bozovic, I.; Xu, X.; Shi, X.; Armitage, N. P.; Crooker, S., *Observation of cyclotron resonance and measurement of the hole mass in optimally doped LaSrCuO*, **Physical Review B** **103**, 134515 (2021) doi.org/10.1103/PhysRevB.103.134515



(A) Time-domain transmission signals through the high- T_c superconducting sample of LSCO at zero field and 31T, resulting from electronically-controlled terahertz optical sampling, coupled to a tabletop 31T pulsed magnet with free-space optical access. **(B)** Optical conductivity $\sigma(\omega)$ of LSCO for right and left circularly polarized THz light. The very broad Drude conductivity peak from the charge carriers shifts by the magnetic-field-dependent cyclotron frequency ω_c . Dashed lines are fits to the data. **(C)** Carrier cyclotron mass ($m_c = eB/\omega_c$) determined from the cyclotron frequency, plotted versus hole doping for a series of LSCO thin films. m_c increases monotonically with p , right through the critical doping $p^* \sim 0.19$.