Circular polarization immunity of the cyclotron resonance photoconductivity in two-dimensional electron systems

E. Mönch¹, P. Euringer¹, G.-M. Hüttner¹, I. A. Dmitriev¹, D. Schuh¹, M. Marocko¹, N. N. Mikhailov², S. A. Dvoretsky², K. Watanabe³, T. Taniguchi³, J. Eroms¹, D. Bougeard¹, D. Weiss¹ and S. D. Ganichev¹

¹Terahertz Center, University of Regensburg, 93040 Regensburg, Germany
²Rzhanov Institute of Semiconductor Physics, SB RAS, Novosibirsk, 630090 Russia
³Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan
⁴International Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

Abstract— Two-dimensional electron systems (2DES) subjected to a perpendicular magnetic field absorb electromagnetic radiation via cyclotron resonance (CR). Here we report a qualitative deviation from this well-known behavior. Our measurements in large-sized 2DES based on GaAs and HgTe reveal that the CR-enhanced photoconductivity becomes insensitive to the radiation helicity, showing almost the same signal amplitude for both CR active and inactive polarities of $B$, when the temperature $T$ is lowered to that of liquid helium or below. Strikingly, the simultaneously measured CR in the transmission demonstrates a conventional strong helicity dependence for all $T$. In contrast similar photoconductivity measurements in graphene show no anomalies indicating an ordinary helicity-sensitivity in the whole investigated temperature range.

I. INTRODUCTION

SINCE the first observation of the cyclotron resonance (CR) in 1953 [1] it is known that for the circularly polarized radiation propagating along or against the magnetic field direction (Faraday geometry) the resonance is possible for one polarity of the magnetic field only (CR active polarity). The obvious reason for that is that resonant acceleration is only possible when the electric field of the wave rotates synchronously and in the same sense as the positively charged carriers performing the cyclotron motion (or in the opposite sense for the negatively charged electrons). The strong asymmetry with respect to polarity of $B$ or helicity of the incoming wave is confirmed by many CR experiments and is widely used to determine the sign of charge of the conduction carriers.

Under the condition of CR absorption in a static magnetic field $B$, the electromagnetic wave with the frequency $\omega_{\text{CR}} = eB/m^*$ is resonantly absorbed by the charged carriers, which are accelerated in their spiral or circular cyclotron orbits. Basic experimental approaches to CR investigations include (i) radiation transmission/reflection, (ii) photoconductivity, and (iii) quenching of the photoluminescence due to the CR absorption. The transport approach using microwave and terahertz photoconductivity/photore sistance, also known as a cross-modulation method, has been initially suggested for the CR studies by Zeiger et al. in 1958 [2]. A distinctive advantage of this technique where the sample itself acts as a detector of the CR is that it can be applied even to micrometer-size structures in which reliable transmission and reflection measurements become challenging or impossible.

Fig. 1. Panel a) illustrates the transmitted signal measured at $T = 2$ K in the GaAs for right-handed radiation helicity. The curve is recorded as a response to radiation's frequency of $f = 0.69$ THz and was normalized to the value at $B = 0$. The black vertical arrow depicts the cyclotron resonance position labeled with CR. Panel b) shows the corresponding photoresistance, $\Delta R_p$, normalized to its maximum value $\Delta R_p^{\text{max}}$. The curves were measured for a set of temperatures ranging from $T = 25$ K down to 2 K each shifted for clarity by $\Delta R_p/\Delta R_p^{\text{max}} = 1.5$. The temperatures correspond to the traces illustrated with the same color.

In strong contrast to natural expectations, our present experiments on several GaAs- and HgTe-based two-dimensional electron systems (2DES) reveal the CR-enhanced photoconductivity which becomes insensitive to the radiation helicity when the measurement temperature $T$ is lowered to that of liquid helium or below: The amplitude of the CR signals...
excited by a circularly polarized terahertz (THz) radiation is observed to be almost the same for both CR active and inactive polarities of $B$ and for both helicities. Strikingly, the conventional behavior of the photoconductivity, where the CR is present for the active magnetic field polarity only, is gradually restored at high $T$. Unlike the photoconductivity, the simultaneously measured CR in the transmission demonstrates such conventional strong helicity dependence for all $T$. Furthermore, we have also studied graphene encapsulated in hexagonal boron nitride where the CR photoconductivity shows no anomalies and remains ordinarily helicity-sensitive in the whole investigated temperature range.

II. RESULTS

Our present experiments, performed on large structures with the lateral size strongly exceeding the THz laser spot, unambiguously demonstrate that: (i) the helicity-insensitive CR photoresponse can be detected in conventional photoconductivity signal which directly reflects the resonant CR absorption and associated heating of electrons, (ii) the anomaly disappears at high temperature, and (iii) the observed immunity is not related to any external factors, like antenna effects or diffraction at the metallic parts of the experimental setup, contacts, or structure edges. We argue that the observed CR anomalies in the photoconductivity can be attributed to an enhanced near-field absorption and suppressed reflection of the THz radiation in the vicinity of strong impurities/defects which can be present in the investigated GaAs- and HgTe-based structures. Such near-field effects can locally destroy the translational and axial symmetries of the electron transport leading to strong mixing of both helicity modes in the screened non-uniform THz field acting on the electrons. These near-field effects should indeed not be visible in transmission measured in the far field at large distance from the sample and can be suppressed at high $T$ where the electron transport is dominated by electron-phonon scattering. Within this interpretation, the CR photoconductivity in response to a circularly polarized THz radiation can serve an indispensable tool to test the technological quality and nature of disorder in high-mobility electron systems.

REFERENCES

[1] G. Dresselhaus, A. F. Kip, and C. Kittel. “Observation of Cyclotron Resonance in Germanium Crystals,” Phys. Rev., vol. 92, pp. 827-827, Nov., 1953.

[2] H. J., Zeiger, C. J., Rauch and M. E., Behrndt, “Observation of Microwave Cyclotron Resonance by Cross Modulation,” Phys. Rev. Lett., vol. 1, pp. 59-60, Jul. 1958.