

Terahertz Detectors based on graphene

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Abstract. In this study we present magnetotransport and magneto-optical data obtained in the magnetic field range $0\text{ T} < B < 7\text{ T}$ at detectors patterned in Corbino geometry on epitaxial graphene wafer using a Ge detector. We observed the cyclotron resonance of charge carriers in these wafers by measurement of the transmission of THz waves through the unpatterned squares (about $4 \times 4\text{ mm}^2$) of the wafers as a function of the magnetic field B applied perpendicular to the wafer. Further, we performed measurements of the photoc conductivity of graphene-based devices shaped in Corbino geometry, induced by terahertz (THz) radiation generated by a p-Ge laser (emitting in the energy range $7.5\text{ meV} \leq E_{ph} \leq 11\text{ meV}$). Our photoconductivity measurement implies that graphene devices are suitable for the detection of terahertz radiation.

1. Introduction

THz radiation is very promising to open new opportunities in many fields such as for example the material research, medical technology and basic astro- and atmosphere physics. Despite these broad application possibilities very few of these opportunities have been exploited up to date. This is also due to the existence of the so called "terahertz gap" that describes the lack of both THz sources and detectors which are both easily and economically to operate. One possibility for the realization of a THz detector is by exploiting the Landau quantization in quantum Hall detectors. To achieve a quantization of 10 meV (corresponding to a wavelength of $124\text{ }\mu\text{m}$ a magnetic field strength of $B \approx 5\text{ T}$ is needed in GaAs [1] and of $B \approx 2\text{ T}$ in HgTe [2]. For graphene on the other hand—fabricated for the first time in 2004 by mechanical exfoliation [3]—calculations predict that a Landau-Level (LL) split of $\Delta E_L \approx 10\text{ meV}$ can be achieved with magnetic fields smaller than 0.5 T [4].

2. Experimental

We investigated two graphene samples (one exfoliated and one epitaxial). The samples were mounted together with a laser system for excitation in a Helium bath cryostat.

The laser system used is based on a p-Ge laser that can be tuned to emit in the energy range between 7.5–11 meV (corresponding to a range in wavelength of 120–180 μm). The laser is operated in pulsed mode with a pulse duration of 0.3–50 μs and a repetition rate of 1 Hz with



a peak power of 1 W. Further details of the laser system can be obtained for example from Ref. [5].

One sample investigated was prepared by mechanical exfoliation from graphite. This sample was then contacted with four gold contacts and used for magnetotransport measurements (without laser excitation). These measurements are done at a temperature of $T \approx 2.8\text{K}$.

The other sample was epitaxially grown on SiC. This sample was then cleaned, etched with Ar/O-Plasma and contacted with a Corbino structure made of Ti/Au. It was then used for photoresponse measurements at a temperature of $T = 4\text{K}$.

3. Results and Discussion

3.1. Exfoliated graphene

In figure 1 we have plotted the resistance of the graphene sample as a function of the backgate voltage for 6 different magnetic fields. We can see the Dirac point at the position of the maximal resistance at around $V_{bg} = 5\text{V}$ in the following called the 0th maximum. In the inset we plotted the difference of the backgate voltages of the 0th and 2nd maximum to the right. According to [6, 7] the energy of a Landau-Level M_n in graphene is given by

$$M_n = \text{sgn}(n) \sqrt{\Delta^2 + 2|n|\hbar v_F^2 eB}, \quad (1)$$

with Δ an energy gap, v_F the Fermi velocity, B the magnetic field and n the quantum number of the LL. In the inset we see that the measured voltage differences fit quite well to the square root dependence in (1) assuming $\Delta = 0$.

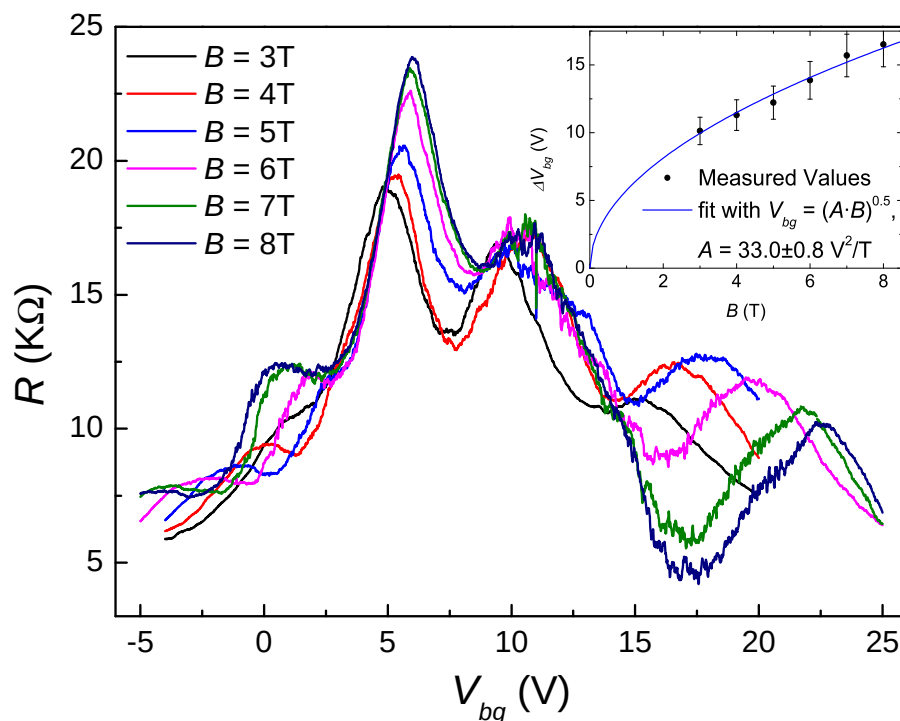


Figure 1: Transport measurements of exfoliated monolayer graphene on a SiO_2 substrate. The Dirac points are located at 5 V, the temperature is 2.8 K and the current is 95 nA. In the inset the difference of the backgate voltages at the 0th and the 2nd maximum is plotted versus the magnetic field.

3.2. Epitaxial graphene

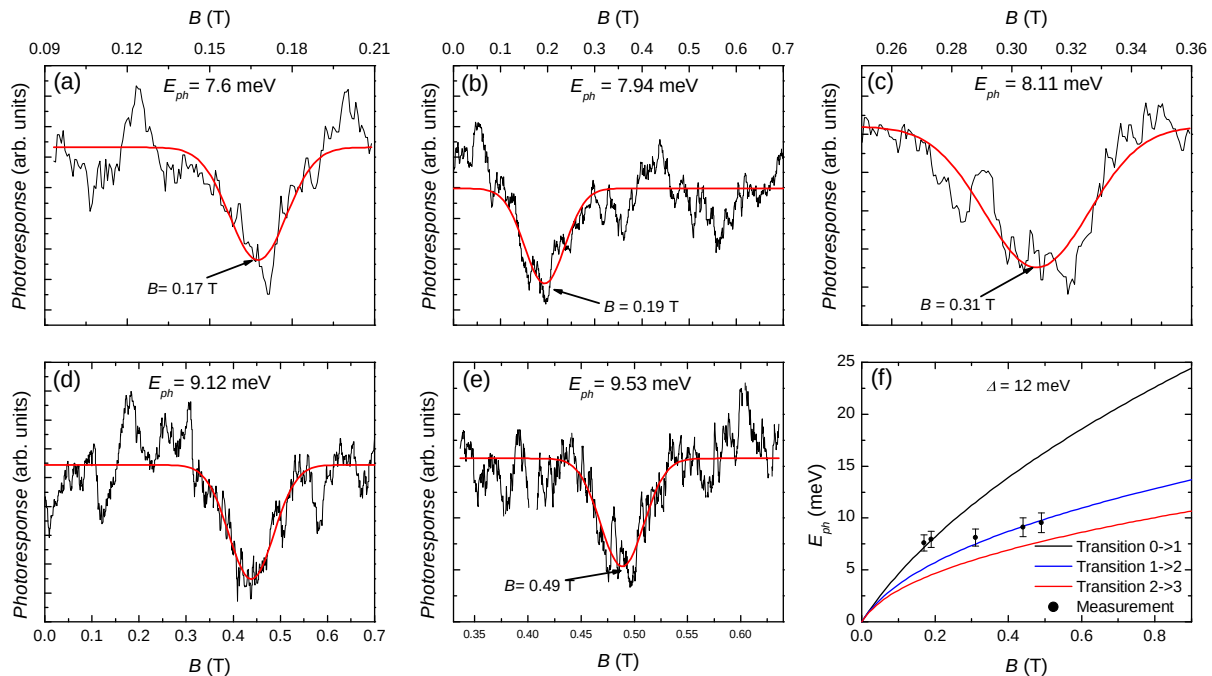


Figure 2: Photoresponse on epitaxial graphene. Figures (a–e) show the photoresponse at different photon energies E_{ph} as a function of the magnetic field B . Figure (f) shows the energy of the main photoresponse peak as a function of the applied magnetic field. Additionally the energies of the intraband Landau level transitions according to (2) assuming $\Delta = 12\text{meV}$ are shown.

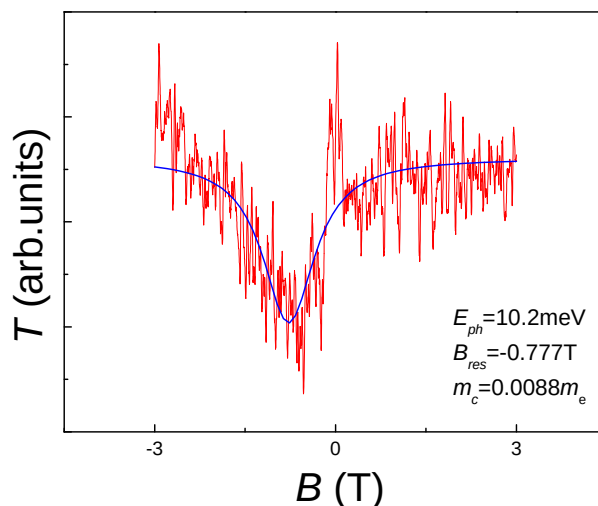


Figure 3: Phototransmission of an epitaxy sample as a function of the magnetic field.

In figure 2(a–e) the photoresponse of graphene for a set of photon energies is given. The photosersponse is strongest at the position of the minima of the photoresponse curves (see fig.2).

Using (1) the energy of the intraband transition between two LLs in the conduction band is given by (only transitions with $\delta n = \pm 1$ are allowed):

$$E_{n+1,n} = \sqrt{\Delta^2 + 2(n+1)\hbar v_F^2 eB} - \sqrt{\Delta^2 + 2n\hbar v_F^2 eB} \quad (2)$$

In figure 2(f) the energies of the transition between two LLs in graphene are plotted as a function of the magnetic field. The measured values for the photoresponse fit quite well to the transitions according to eq.(2) assuming $\Delta = 12\text{meV}$. We attribute this to the opening of a dynamical gap by the intense electric field of the laser[8]. Another hint to the possibility of the opening of a dynamical gap can be found in the transmission curve presented in figure 3. From this transmission measurement we derive a cyclotron mass for the sample of $m_c = 0.0088m_e$ (m_e the electron mass).

References

- [1] Stellmach C, Vasile G, Hirsch A, Bonk R, Vasilyev Y B, Hein G, Becker C R and Nachtwei G 2007 *Phys. Rev. B* **76**(3) 035341
- [2] Gouider F, Nachtwei G, Brüne C, Buhmann H, Vasilyev Y B, Salman M, Könemann J and Buckle P D 2011 *Journal of Applied Physics* **109** 013106 (pages 5)
- [3] Novoselov K S, Geim A K, Morozov S V, Jiang D, Zhang Y, Dubonos S V, Grigorieva I V and Firsov A A 2004 *Science* **306** 666–669
- [4] Salman M, Gouider F, Schmidt H, Vasilyev Y B, Haug R J and Nachtwei G 2011 *physica status solidi (c)* **8** 1208–1210
- [5] Gouider F, Bugár M, Könemann J, Vasilyev Y B, Brüne C, Buhmann H and Nachtwei G 2009 *Journal of Physics: Conference Series* **193** 012066
- [6] Gusynin V P, Sharapov S G and Carbotte J P 2007 *Phys. Rev. Lett.* **98** 157402
- [7] Goerbig M O 2011 *Reviews of Modern Physics* **83** 1193–1243
- [8] Zhou Y and Wu M W 2011 *Phys. Rev. B* **83** 245436