Terahertz high harmonic generation in Dirac materials

J.-C. Deinert[1]
S. Kovalev[1], H. Hafez[2], M. Chen[1], B. Green[1], M. Bawatna[1], S. Germanskiy[1], N. Awari[1], Z. Wang[1], I. Ilyakov[1], D. Turchinovich[2,3], and M. Gensch[4,5]

[1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany
[2]Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany
[3]Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany
[4]DLR, Rutherfordstr. 2, 12489 Berlin, Germany
[5]Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

j.deinert@hzdr.de

The exploration of nonlinear optical phenomena has not only deepened the understanding of light-matter interaction, but it also enabled novel technologies that make use of the resulting synthesis of electromagnetic radiation at new frequencies. Whereas the nonlinear responses of matter in the microwave and optical regimes are well explored, research addressing the intermediate Terahertz (THz) regime is still largely in its infancy, despite its high technological relevance, e.g. for novel high-speed (opto-)electronics.
For these future applications in the THz range, graphene is a highly promising material, because of the unique optical properties originating from its prototypical Dirac-type electronic structure. Soon after its discovery, there have multiple predictions of efficient harmonic generation in the THz range [1, 2], but experimental evidence has remained incomplete. Recently, we experimentally demonstrated the highly efficient THz harmonics generation (HG) in a single layer graphene sample (up to 7th order) at ambient conditions upon excitation with a moderate THz field of only 85 kV/cm (see Fig. 1) [3]. Our observations have been successfully described by a thermodynamic model, which clearly explains the experimentally observed crucial role of the graphene doping level for THz HG [3, 4]. By using gated graphene samples and multilayer structures, we are able to predictably modify the HG efficiency and thereby corroborate the thermodynamic model.

In addition, we employed the same experimental scheme to other Dirac materials, such as topological insulators and Dirac/Weyl semimetals, showing that THz HG is a rather universal phenomenon based on the linear band dispersion in the vicinity of the Dirac point.

References

[1] S. Mikhailov et al., Microelectron. J. 40 (2009) 712.
[2] I. Al-Naib, Phys. Rev. B, 90 (2014) 245423
[3] H. Hafez, S. Kovalev et al., Nature, 561 (2018) 507
[4] Z. Mics et al., Nat. Commun., 6 (2015) 7655

Figures

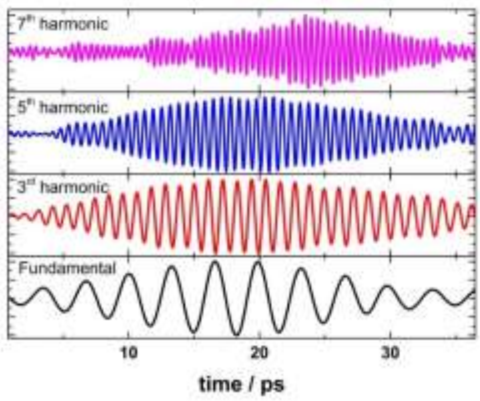

Figure 1: Time-domain THz field traces of fundamental and harmonics up to 7th order in single-layer graphene [3].