# Ultrafast detection from 0.6 THz to 33 THz employing graphene flakes

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Graphene can serve as an excellent active material for the development of ultrafast electro-optic devices. With the vanishing bandgap, photons can be absorbed via interband processes over an extremely wide spectral range (from ultraviolet to far-infrared). However, in the regime of non-zero Fermi energy and very low photon energies, interband absorption can be prohibited. In this case intraband absorption is an efficient process. T. Müller et al. [1] presented an ultrafast detector for the near-infrared range. Their device was operated at room temperature and reached frequencies of up to 16 GHz. Field-effect transistors made of graphene flakes have been employed for the detection of THz radiation. Vicarelli et al. [2] developed a very sensitive detector for cw radiation at room temperature, while Yan et al. [3] presented an ultrafast bolometer which was cooled to 4 K.

We present a detector based on a graphene flake for a very broad spectral range from 0.6 THz to 33 THz, corresponding to wavelengths of 500 µm to 9 µm, respectively. To couple the far-infrared radiation efficiently to the flake, which is orders of magnitude smaller than the largest wavelengths, a logarithmic periodic antenna [5] is patterned on top of the substrate. The antenna is connected to the graphene flake by an interdigitated structure (see fig. 1). A coaxial cable, bonded to the outer part of the two antenna arms, serves as signal line. The signal is amplified by a high-frequency amplifier and recorded with a fast sampling oscilloscope with a bandwidth of 30 GHz.

The free-electron laser (FEL) FELBE at the Dresden lab served as radiation source for the characterizing the detectors at wavelengths of up to 220 µm. Additional data were obtained using a THz gas laser at the University of Regensburg providing radiation pulses with wavelengths of up to 500 µm. The response time of the devices is about 50 ps, which highlights the potential of this detector for timing measurements of intense THz pulses. The signal of two FEL pulses with a temporal delay of 500 ps is shown in fig. 2. The pulse energy of each of the pulses was about 40 nJ, which lead to a signal amplitude of 30 mV. Despite a low responsivity of about 5 nA/W, pulses with energies down to 1 nJ can be resolved. For high pulse energies, the signal amplitude saturates strongly. While this saturation limits the dynamic range for linear detection, it can be exploited in autocorrelation measurements [6]. In this regime the response time is not limited by the RC time constant but by the intrinsic response time of the graphene flake (< 10 ps).

Furthermore we demonstrate the important role of the substrate for these devices. Our first devices were produced on $SiO_2$ on Si [7]. When a low-resistivity substrate is used, the high-speed performance of the device is strongly deteriorated. The antenna forms a capacitor with the conductive substrate material and therefore increases the RC time constant of the detector. Devices on high-resistive Si could resolve fast signals only for wavelengths above 20 µm. This can be attributed to phonon-related absorption in the Si substrate resulting in higher substrate conductivity due to thermally activated carriers. To overcome this restriction, a new set of detectors has been fabricated on semi-insulating SiC. As graphene is nearly invisible on top of SiC, graphene grown by chemical vapor deposition on copper was transferred to the new substrate and located by Raman mapping. With these new devices FEL pulses can be measured down to a wavelength of 9 µm.

## References

[1] T. Müller et al., Nature Photon. **4**, 297 (2010).
[3] L. Vicarelli et al., Nature Mat. **11**, 865 (2012).
[4] J. Yan et al., Nature Nanotechnol. **7**, 472 (2012).
[5] R. Mendis et al., IEEE Antennas and Propag. Lett. **4**, 85 (2005).
[6] S. Winnerl et al., Appl. Phys. Lett. **73**, 2983 (1998).
[7] M. Mittendorff et al. Appl. Phys. Lett. **103**, 021113 (2013).

**Figures**

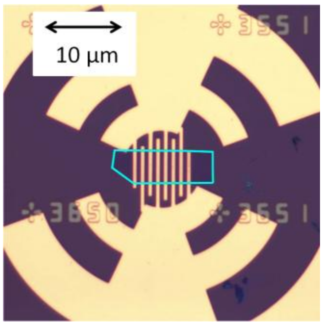


Figure 1: Design of the detector: The graphene flake is in the blue box in the center, the antenna is connected to the flake by an interdigitated structure.

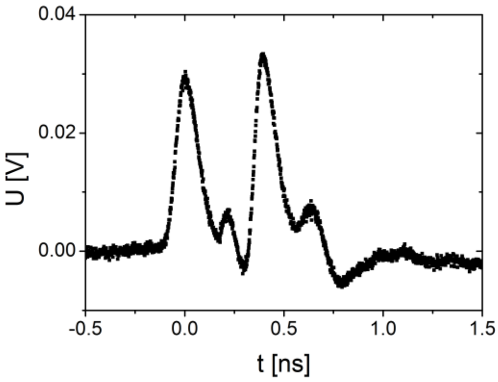


Figure 2: Signal of two FEL pulses with a temporal delay of 500 ps at a wavelength of 42 µm.