On/off in trillionths of a second: Optically controlled magnetic fields

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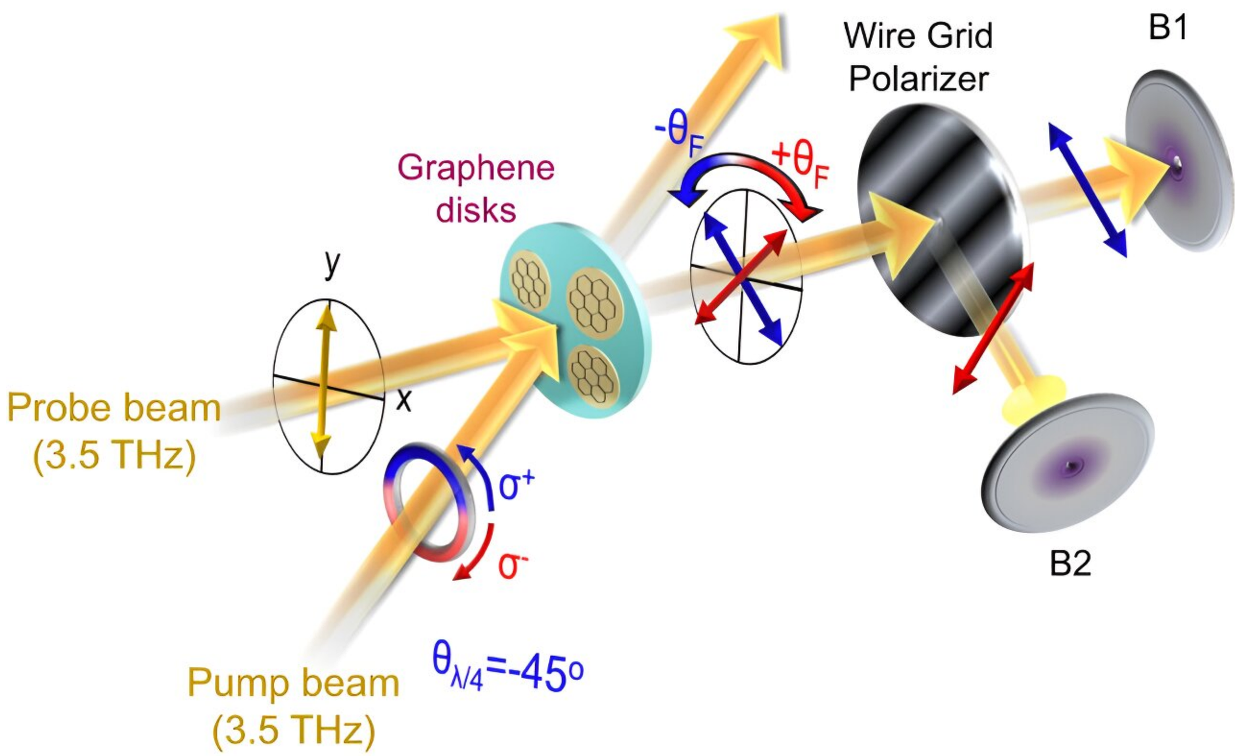
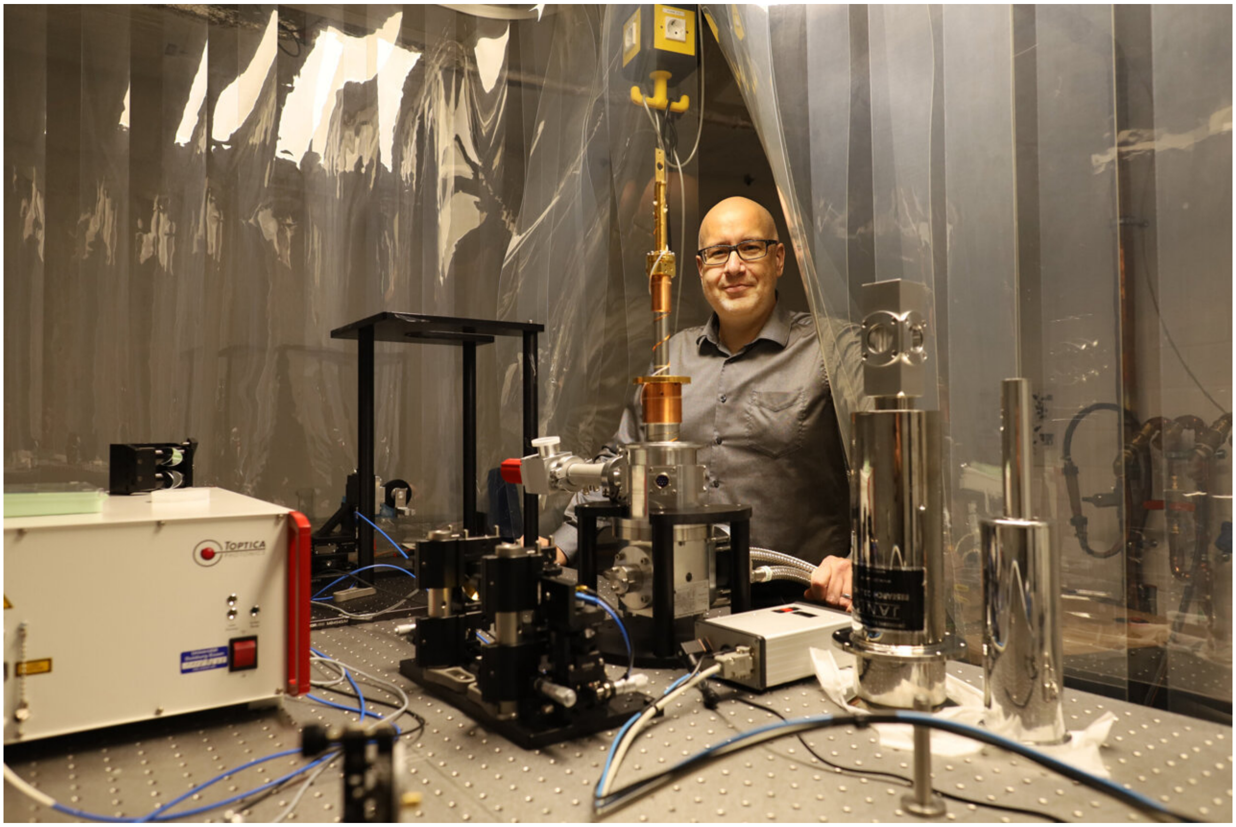


Schematic of the experiment for pump-induced Faraday rotation θ_F on graphene disks. The frequency of the probe and pump beam is set to 3.5 THz. A quarter wave plate (λ/4 plate) is located in the pump beam path. Its rotations of -45^o and $+45^o$ generate the left (σ^+)—and right (σ^-)—handed circularly polarized pump beam. The probe beam is linearly polarized in the vertical direction, the sign of θ_F denotes its direction. A wire grid polarizer is located in the probe beam path and it is aligned to 45^o with respect to the incident probe beam. The reflected and transmitted probe beams from the wire grid polarizer are guided to bolometers B2 and B1, respectively. Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-43412-x

Physicists at the University of Duisburg-Essen and their cooperating partners have discovered that tiny graphene sheets can become electromagnets under infrared radiation. The study is published in the journal *Nature Communications*.

The sample itself is invisible to the human eye: There are tiny disks on a 2 x 2 millimeter surface, each with a diameter of 1.2 micrometers, just one hundredth the width of an average human hair. They consist of two layers of graphene—two sheets of carbon atoms that lie on top of each other like pancakes. Their electrons move freely in the material and can be influenced by electromagnetic fields.

The working group of Prof. Dr. Martin Mittendorff from Experimental Physics at the University of Duisburg-Essen (UDE) has been investigating waves in electron systems, so-called plasmons, within the Collaborative Research Center 1242 for years. In this case, the team used circularly polarized terahertz (THz) radiation in the infrared range to excite the electrons. "You can think of the graphene sheets as buckets filled with water—the electrons," explains Mittendorff. "If you stir the inside of the bucket with a stick, circular currents begin to form."



Prof. dr. Martin Mittendorff behind the experimental setup. Credit: UDE/Andreas Reichert

In analogy, the charge carriers excited by the corkscrew-shaped THz radiation move in a circular motion in the disks and thus act like tiny electromagnets. Within the experiment, magnetic fields in the range of 0.5 Tesla were generated; this equates to around 10,000 times the Earth's magnetic field. The frequency of the plasmon can be adjusted via the diameter of the graphene disk. In terms of their effect, the tiny disks are comparable to strong permanent magnets, but they can be switched on or off within picoseconds—in other words, in a trillionth part of a second.

Although the experiments are basic research, there are realistic potential applications: By using graphene disks, the physicists have developed optically switched magnetic fields that can be used to influence other materials in the vicinity. In quantum dots that illuminate screens, for example, the color of the light can be adjusted. As for magnetocaloric materials, they change their temperature depending on the magnetic field applied.

This publication is the result of a collaboration between the Mittendorff working group and national and international partners: The graphene disks were manufactured at the University of Maryland (U.S.) and the measurements were carried out at the Helmholtz-Zentrum Dresden-Rossendorf.

More information: Jeong Woo Han et al, Strong transient magnetic fields induced by THz-driven plasmons in graphene disks, *Nature Communications* (2023). DOI: 10.1038/s41467-023-43412-x

Provided by University of Duisburg-Essen