Flying Doughnut Pulses – a Route to Isolated gigaGauss Magnetic Fields

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Introduction: Ultrafast magnetic fields are usually produced by an ultrafast current driven in metals, but the rise and fall times are limited by circuit inductance. Lasers offer options that minimize induction or even side-step the problem altogether. We will discuss some of the options and demonstrate one. Our short-term aim is to generate a Tesla-scale magnetic field lasting a few picoseconds. Long-term we aim to generate 30 THz gigaGauss fields.

Semiconductors: When light is incident on a semiconductor it creates a photoelectron wave packet if it has sufficient photon energy. If the photon is in the bandgap, however, the lowest order process is a two-photon transition.

Therefore, it is possible to produce a wave packet in the conduction band by a single photon transition with a second harmonic beam and to produce an almost identical wave packet via a two-photon transition using the fundamental. As we will show, these two wave packets interfere, allowing us to control the direction of the resultant electron wave packet [1]. If one or both pulses are short, the controlled wave packet is also short as is the THz emission that follows.

We use azimuthal polarization for both wave packets and thus create a ring current and a magnetic field as described by the Biot-Savart law and shown in the figure.

In GaAs using 1.48 µm light and its second harmonic, we create a current that we can image by scanning a pixel detector [2]. Azimuthally polarized THz radiation (Fig. 1) results from this current. By improving the efficiency of our THz telescope, we now reach the peak intensity of 3 mTesla. Next, we will use higher pump power and search for the most efficient semiconductor.

Gases: Gases allow much higher fields to drive the current and they offer a vacuum in which to emit electrons. However, gases are much harder to use than solids. With our extensive experience from attosecond science, we model a breakdown plasma. Using azimuthal polarization to break down Helium, we predict fields exceeding 8 Tesla and we think this can be optimized to much higher THz fields [3].

Lasers: A physical current in a medium is one way to produce THz isolated magnetic fields but isolated fields are also found in the near field of strongly focused laser beams. At 30 THz, CO2 is the longest wavelength of the high energy storage lasers. At high pressure, it can produce energetic (15 Joule) pulses with duration of 2.5 ps and pulse compression, although not well developed in the mid infrared, has been demonstrated [4].

Since CO_2 lasers are insensitive to polarization, low power azimuthal pulses can be amplified. Assuming single period 1-Joule pulses in an azimuthally polarized beam, we can reach an isolated field of 10^9 Gauss near field.

References

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