Generating Tesla Magnetic Pulses in Plasmonic Nanostructures

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Abstract: Bimetallic plasmonic ring resonators illuminated by femtosecond laser pulses generate transient sub-picosecond thermoelectric currents and nanoconfined Tesla-scale magnetic fields.

Magnetic sources with high spatial and temporal resolution are crucial in order to study and understand ultrafast magnetic phenomena. However, there is currently no practical method that meets these criteria. Here we introduce a metamaterial source that allows for direct generation of ultrafast Tesla-scale magnetic pulses localized at the nanoscale.

We study numerically the response of bimetallic ring resonator arrays consisting of ¾ Au and ¼ Ni with a mean diameter of 60 nm and a cross-section of 50x50 nm^2 (see Fig. 1a). When illuminated with linearly polarized, ultrafast pulses, centered at 940 nm, the combination of the bimetallic nature of the rings and the polarization of the incident field, leads to strongly non-uniform resonant absorption and hence to a steep gradient of the electron temperature across the circumference of the ring (top inset of Fig. 1b). This temperature difference produces diffusion of charged carriers in the two metals (Seebeck effect). Since the charged carriers are electrons in Au and holes in Ni, the result of the diffusion process resembles two voltage sources connected in series as seen in Fig. 1a, resulting in a unipolar circular thermal current accompanied by a magnetic field oriented normal to the ring plane. The resulting coupled heat-transfer/electromagnetic problem is solved numerically using a finite element method following a two-temperature model for the electrons and the atomic lattice. The temperature difference between the Au/Ni junctions reaches up to 4000 K (top inset of Fig. 1b), leading to an extremely high current density of 10^{13} A/m^2, which in turn results in a magnetic field with peak value of 0.35 T, confined to the inner area of the nanoscale rings. The lifetime of the transient current and accompanying magnetic fields is mainly controlled by the relaxation of the electrons through collisions with phonons, which results in an ultrafast, 750 fs, magnetic pulse (Fig. 1b).

In conclusion, we show that bimetallic ring arrays illuminated by ultrafast laser pulses support transient thermal currents leading to strong sub-picosecond magnetic pulses. Our results facilitate investigations of ultrafast magnetic phenomena and are of interest for applications in material characterization and magnetic recording.

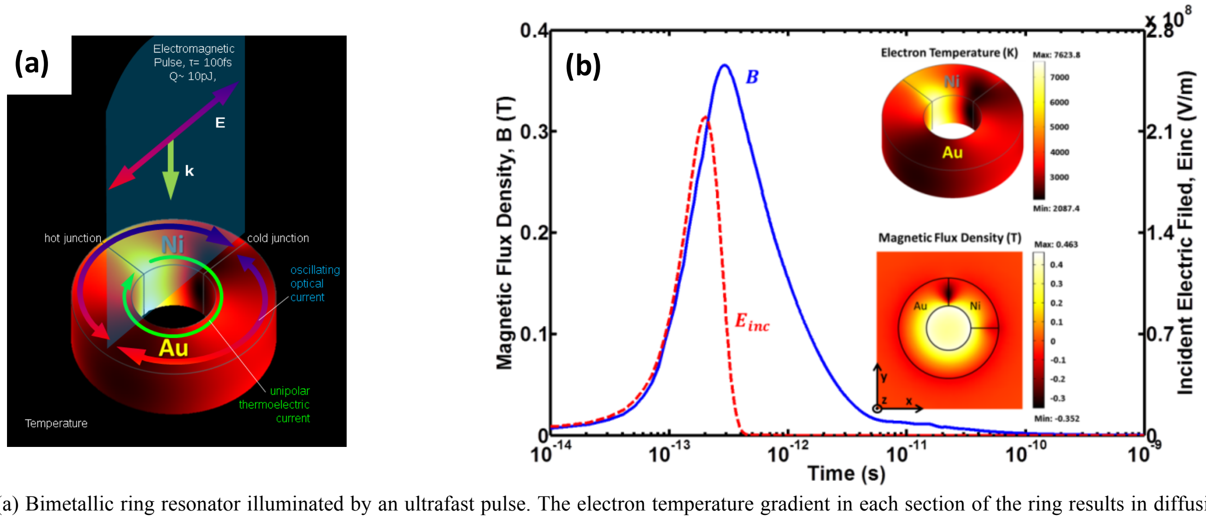

Fig1. (a) Bimetallic ring resonator illuminated by an ultrafast pulse. The electron temperature gradient in each section of the ring results in diffusion of charged carriers similar to two voltage sources connected in series. (b) Time evolution of the numerically calculated magnetic flux density (solid blue) averaged over the inner area of the ring under excitation with an ultrafast pulse (red dashed). The electron temperature and magnetic field distribution at the peak of the magnetic flux are shown in the top and bottom insets, respectively.