Optical Excitation of Unipolar Tesla Magnetic Pulses in Plasmonic Nanostructures

E. Atmatzakis[1], A. Tsiatmas[1], N. Papasimakis[1], V. Fedotov[1], B. Luk'yanchuk[2], F. Javier Garcia de Abajo[3] and N. I. Zheludev[1,4]

1. *Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, Southampton SO17 1BJ, United Kingdom,*
2. *Data Storage Institute, Agency for Science, Technology and Research, Singapore 117608*
3. *Instituto de Química Física Rocasolano - Consejo Superior de Investigaciones Científicas, Serrano 119, 28006 Madrid, Spain*
4. *Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore*

The study of ultrafast magnetic phenomena underpinning the development of data storage technologies requires increasingly high spatial and temporal resolution. However, to date there is no easily accessible method that meets these criteria. Here we introduce a plasmonic source that allows for direct generation of unipolar, sub-ps, 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 to Fig. 1b). Due to the Seebeck effect, this temperature difference will cause diffusion of charged carriers in the two metals. Since the charged carriers are electrons in Au and holes in Ni, the result of the diffusion process will resemble 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 by a finite element solver following a two-temperature model. The temperature difference between the Au/Ni junctions reaches up to 4000 K (top inset to 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 in 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 magnetic pulses of sub-ps duration. Our results will facilitate investigations of ultrafast magnetic phenomena and will be of interest for applications in material characterization and magnetic recording.

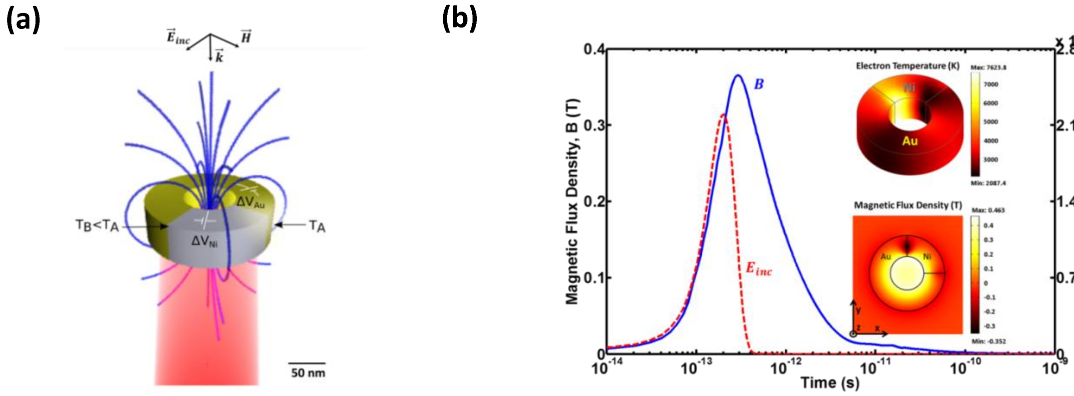

Fig1. (a) Bimetallic ring resonator illuminated by an ultrafast pulse. The electron temperature gradient in each section of the ring results in diffusion of charged carriers similar to two voltage sources connected in series. **(b)** Time evolution of the numerically calculated magnetic flux density (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.