Strong-Field-Induced Attosecond Magnetism

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Magnetism is one of the most fundamental physical phenomena in nature. In the past decades, immense efforts were devoted to understanding and manipulating magnetism on ultrafast timescales[1]. However, in all works to date the fastest magnetic response was on the order of few femtoseconds[2,3], and it is not yet clear what the fundamental speed-limit is. Moreover, a magnetic turn-on has not been observed or predicted using linearly-polarized light.

Here we theoretically explore light-driven magnetism in materials that are non-magnetic in their ground state with time-dependent density functional theory (TDDFT)[4]. First, we show that with circularly-polarized driving in the strong-field regime, the system develops an onset of magnetization within a few femtoseconds (see Fig. 1(b)). We find this effect originates from a sub-cycle timescale cascaded transfer process of light's spin angular momentum (SAM) to electronic orbital angular momentum (OAM), which is then transferred to spin angular momentum (through spin-orbit coupling (SOC)) (see Fig. 1(a)). This understanding leads us to propose a new paradigm for inducing attosecond magnetism: By irradiating optically-anisotropic heavy materials with intense linearly-polarized light, purely transient magnetism arises (the slower femtosecond response is suppressed). The induced magnetization then follows the sub-cycle structure of the electronic orbital angular momentum transfer, which is extremely nonlinear and comprises of high-order harmonics of the laser. Consequently, we predict the fastest magnetic responses to date of ~500 attoseconds, and propose an X-ray circular-dichroism (CD) transient absorption set-up that is capable of measuring such fast phenomenon (Fig. 1(c)). Our work presents a direct path to control the speed of magnetization dynamics down to their potential intrinsic limit – the attosecond motion of electrons in their natural timescale.

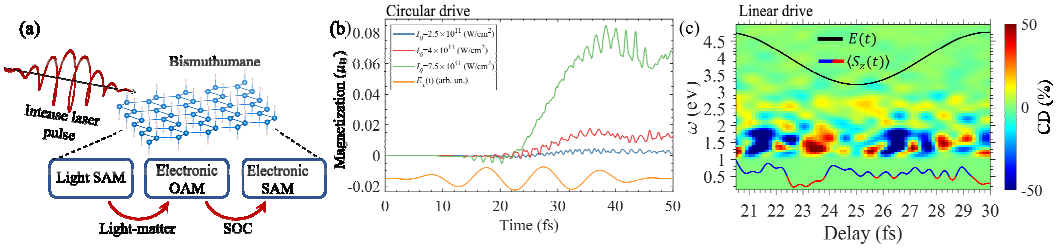

Figure 1: (a) Scheme and physical mechanism illustration. (b) light-induced magnetization in circular driving conditions showing femtosecond turn-on of magnetization. (c) Bottom inset is the same as (b), but for linear driving conditions. The 2D map presents simulated pump-probe CD transient absorption, showing that the magnetic response can be observed, including typical ~500 attoseconds oscillations.

References

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