Nonlinear dynamics in novel plasmonic and spintronic systems

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Nonlinear optical processes are vital for fields including telecommunications, signal processing, data storage, spectroscopy, sensing, imaging and computing. However, practicable optical nonlinearities are difficult to achieve due to fundamental physical limitations. Indeed, nonlinear optical interactions are possible mostly when high-power laser light and certain natural or artificial optical materials are combined together. This challenge shapes the current efforts in the field of nonlinear photonics aimed at achieving strong optical nonlinearities on demand using low-power light and nanostructures [1]. However, despite the recent progress in this area, even the strongest nonlinear optical effects observed to date are much weaker than ordinary nonlinear effects observed in many other common physical systems [1]. For example, in many acoustic systems nonlinear effects are so strong that special technical measures need to be taken to eliminate them. Therefore, it has been suggested that the robustness of acoustic nonlinear effects could be transposed to the optical domain and used in photonic devices [1]. The first part of this talk focuses on potential implementations of this idea.

It is well-known that liquid drops, gas bubbles and vibrations, which are ubiquitous in both everyday life and technology, exhibit intriguing nonlinear dynamics phenomena [2, 3]. For example, using a low-pressure ultrasound wave propagating through a liquid with gas bubbles one can readily generate up to 20 higher-order harmonics of the fundamental ultrasound frequency. This is a remarkable results when compared with the ability of nonlinear-optical systems to reliably generate just several harmonics of the fundamental frequency of the incident high-power laser light. Exploring this topic further, we demonstrated that liquid nanodroplets of gallium and its metal alloys exhibit both conventional plasmonic effects in the UV spectral range and nonlinear vibrations. We observed that nonlinear deformations of the surface of the droplets change their plasmonic properties in a very fascinating way [1]. We also theoretically demonstrated that cavitation (violent collapse) of a gas bubble near a liquid metal surface can result in strong emission of UV light through the effect called sonoluminescence, and that so-generated light can, in turn, excite surface plasmon resonances at the interface between the liquid metal and the liquid hosting the bubble [4].

The second part of the talk focuses on nonlinear dynamics in spin-torque nano-oscillators (STNOs) equipped with a delayed feedback circuit. Such STNOs can be used to remember and recognise patterns and therefore are promising candidates for physical reservoir computing (RC) systems [5-7]. Whereas RC has already been demonstrated in delayed-feedback STNOs [5], those systems employ vortex-type STNOs but the feedback signal is obtained by passing the envelope of the signal generated by the oscillator through a diode. Here, we suggest that non-vortex STNOs—those that rely on the ferromagnetic resonance (FMR) effect to generate microwave oscillations [8, 9]—can be used in RC systems. We also demonstrate the possibility of creating a feedback circuit using the delayed signal generated by the oscillator without passing it through a diode.

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