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RESEARCH HIGHLIGHT

Lasing spaser in two-dimensional plasmonic crystals

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The laser is arguably the most important and versatile optical device. Invented just over 50 years ago,[1] the laser has found immense number of uses from fundamental science and ultra-precision metrology to diverse applications in telecommunications, entertainment, computers, displays, biomedicine, materials processing, defense and homeland security and so on. These are based on fundamental property of the laser to generate coherent light that can be focused to microscopic areas or concentrated in pulses as short as 100 as (1 as $=10^{-18}$ s). Still, quest for new lasers continues, in particular, to design the smallest and thinnest lasers possible. This is important in many respects, in particular, because such lasers can be directly modulated with a very high frequency. One way to achieve this goal is provided by invention of the spaser (Surface Plasmon Amplification Stimulated Emission of Radiation),[2] also called plasmonic laser, about 10 years ago. Replacing light quanta—photons—of the laser with electronic excitations at the surface of metals called surface plasmons, which can have atomic-scale dimensions, the spaser itself can be as small or as thin as the dimension of only hundreds of atoms. This is at least thousand times smaller or thinner than smallest existing lasers. However, such a small spaser produces very little light and that light is not collimated into a narrow beam. A team of scientists from the Northwestern Universitiy (USA) headed by George Schatz and Terry Odom has recently designed and demonstrated[3] the thinnest laser to date: a plasmonic laser consisting of a periodic array of metal nanoparticles (see Figure 1a) covered with a nanolayer of organic dye that serves as its gain medium.

Such a system has some properties of lasing spaser, which was proposed in the study by Zheludev *et al.*[4] as a periodic array (two-dimensional metamaterial). It consists of separate spasers oscillating in phase synchronized by their interaction, emitting coherent radiation normally to the array's surface. As happens in today's high-rate competitive science, simultaneously and independently, another lasing plasmonic array (plasmonic crystal consisting of nanoholes in a gold nanofilm over InGaAs semiconductor gain medium) has been demonstrated.[5]

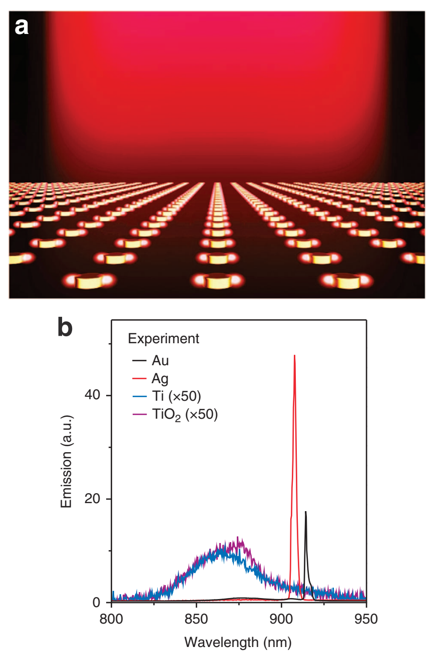

Figure 1 (**a**) Schematic of plasmonic laser (or, lasing spaser) built of a rectangular periodic array (plasmonic crystal) of gold nanoparticles. These are covered by a nanolayer containing dye molecules. When excited by external laser source, the excitation energy is transferred to the gold array whose nanoparticles experience in-phase plasmonic oscillations, schematically shown in the figure. These cause coherent infrared laser radiation normal to the array plane depicted as the red beam (Courtesy of T Odom). (**b**) Emission spectra of nanoparticle arrays of gold (black), silver (red), titanium (blue) and titanium dioxide (purple). The gold and silver arrays show infrared lasing as witnessed by narrow and intense emission light shifted from the center of gain medium fluorescence at $\sim$870 nm (the frequency walk-off or cavity-pull phenomenon well-known for lasers and spasers). Adapted by permission from Macmillan Publishers Ltd.

The nanoplasmonic laser[3] generates coherent light with a narrow spectral line (Figure 1b) that is significantly shifted from the center of the gain medium fluorescence, which is a sign of lasing. This line is slightly red-shifted for gold nanoparticles with respect to silver ones, as is expected from plasmonic properties of these metals. As a control, similar arrays with non-plasmonic materials (titanium or a titanium dioxide) do not show any signs of lasing, which fact independently confirms the plasmonic nature of the observed lasing (spasing). Being a thinnest ($\sim$100 nm) laser, the lasing spaser[3] promises new applications ranging from displays to high-speed communications and beyond.

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