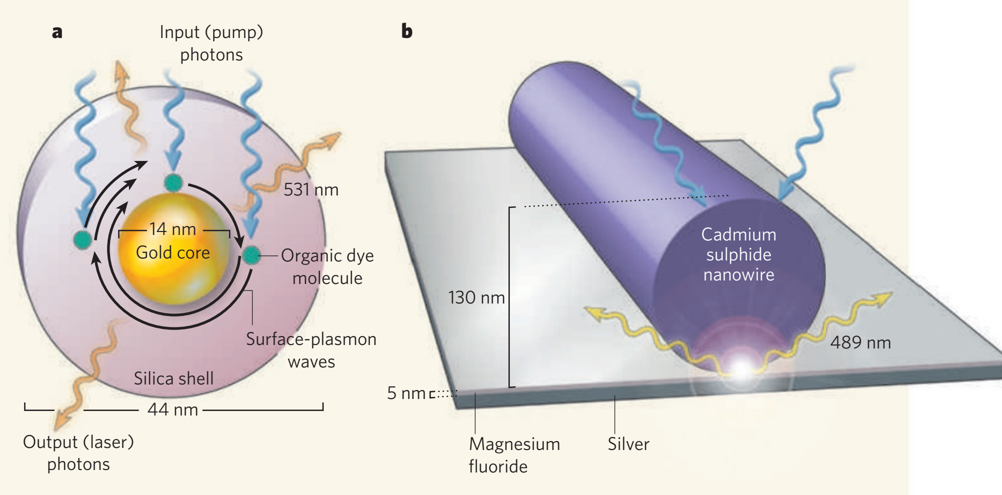

Figure 1 | Plasmon-based nanolasing. **a,** The laser structure developed by Noginov and colleagues[1] consists of a gold core surrounded by a silica shell in which organic dye molecules are embedded. The molecules provide the laser's optical gain. The energy (photons) pumped into the system is transferred to the collective motion of the electrons on the gold core's surface and stimulates the coherent emission and amplification of so-called surface-plasmon waves. These waves are ultimately converted into laser light of wavelength 531 nm. **b,** Oulton and co-workers' laser[2], whose working principle is also based on surface-plasmon waves, consists of a cadmium sulphide nanowire separated from a silver surface by a 5-nm insulating gap made of magnesium fluoride. The emergent, 489-nm-wavelength laser light is emitted from a strongly confined spot within the gap region.

to the laser cavity's optical-feedback property, are all emitted coherently — that is, they have the same frequency and are in step with one another.

The external input of energy typically involves an electric current (electrical pumping) or light illumination (optical pumping). In certain respects, lasing bears some resemblance to the tuning up of an orchestra before the start of a concert. Musicians 'pump' their instruments to emit a single frequency, 'stimulated' by the notes played by their fellows. As the tuning goes on, the concert hall is increasingly filled with sound (albeit not coherent) that may eventually spread out through the open doors of the hall.

The quest for ultra-compact lasers of nanometre scale has faced a fundamental obstacle: the diffraction limit. By conventional means, light cannot be focused down to a spot smaller than around half its wavelength. For visible light, whose wavelength ranges between 300 and 800 nanometres, the smallest dimension of both the spot and the laser cavity is limited to a few hundred nanometres. A feasible way to overcome this limitation is by using a metallic cavity, which can confine light within dimensions markedly smaller than the light's wavelength.

This ability stems from the existence of collective, wave-like motions of free electrons on a metal surface, termed surface plasmons. These oscillations generate electromagnetic waves that are strongly localized at the surface. In this context, and by analogy with the laser, the idea of a spaser (surface plasmon amplification by stimulated emission), in which plasmons play the part that photons do in conventional lasers, was proposed[3,4]. Importantly, surface-plasmon oscillations can be coherently coupled to light outside the metallic cavity, and hence can be exploited to realize ultra-small lasers.

The main obstacle to attempts to produce a plasmon-based laser has been the (resistive) energy losses in the metal from which the cavity is made. Several experimental studies[5,6] have, however, demonstrated that the incorporation of an optical-gain medium into the system can compensate for such losses. Along these lines, Hill and co-workers[7] reported lasing from an electrically driven, metal-coated cavity with dimensions of 200–300 nm.

The present investigations, carried out by Noginov *et al.*[1] and by Oulton *et al.*[2], provide a major step forward for plasmon-based nanolasers. In Noginov and co-workers' experiments[1], gold nanoparticles are encapsulated in silica spheres of 44 nm diameter (Fig. 1a). The optical gain is supplied by organic dye molecules embedded in the silica shells, which are optically pumped; the surface plasmons are provided by the gold cores. The energy pumped into the shells is transferred to the surface plasmons and stimulates the coherent emission and amplification of surface-plasmon waves. Finally, these waves are converted into visible laser light of wavelength 531 nm, which radiates outside the spheres. Although Noginov and colleagues' experiments were performed using an ensemble of silica spheres instead of a single one, the authors argue that the observed laser light was produced by the single spheres independently, rather than being a collective phenomenon.

The laser developed by Oulton and co-workers[2] is a single hybrid surface-plasmon cavity-waveguide structure that consists of a high-gain cadmium sulphide semiconductor nanowire separated from a flat silver surface by a 5-nm insulating gap (Fig. 1b). The authors' experiments and theoretical simulations suggest that the relevant dimension of the cavity, and hence the size of the laser spot, is of the order of 25 nm, around 20 times smaller than the laser's operating wavelength of 489 nm. The laser spot size is controlled by the width of the insulating gap and the diameter of the nanowire. In contrast to standard nanowire lasers[8], there is no cut-off laser size below which the strongly confined surface-plasmon waves cease to exist. Therefore, the expectation is that even smaller plasmon-based lasers can be realized if the width of the gap is reduced further.

Although the two studies[1,2] offer considerable advances in plasmonic-laser science, issues remain that must be tackled before a fully operative plasmonic nanolaser can be realized. One issue is the degree to which the emitted laser light is coherent, a key laser property that has not been explicitly measured by the authors[1,2]. Another troublesome point is related to the lack of collimation of the emergent laser light — in the experiments, converting surface-plasmon waves into conventional laser light resulted in light propagation in all directions.

As far as realistic applications go, electrical pumping would be more compatible with standard technologies than the optical pumping used in the two experiments[1,2]. Nevertheless, the presence of a semiconductor material in the hybrid scheme developed by Oulton and colleagues ensures that their plasmonic laser could also be driven by electric currents. In both experiments, surface plasmons were exploited merely to implement ultra-small, nanometre-scale lasers. An exciting perspective to be explored is using the devices as pure spasers — that is, as sources of coherent surface plasmons. This would pave the way to a new type of nanocircuitry based entirely on surface plasmons. ■

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Correction

In "Gamma-ray bursts: Maybe not so old after all" by Enrico Ramirez-Ruiz and William Lee (*Nature* **460,** 1091–1092; 2009), an editorial error introduced the statement that GRB 070714B is "slightly more than 8 billion parsecs away". The correct units are light years, not parsecs.