Photon-plasmon nanowire laser offers new opportunities in light manipulation

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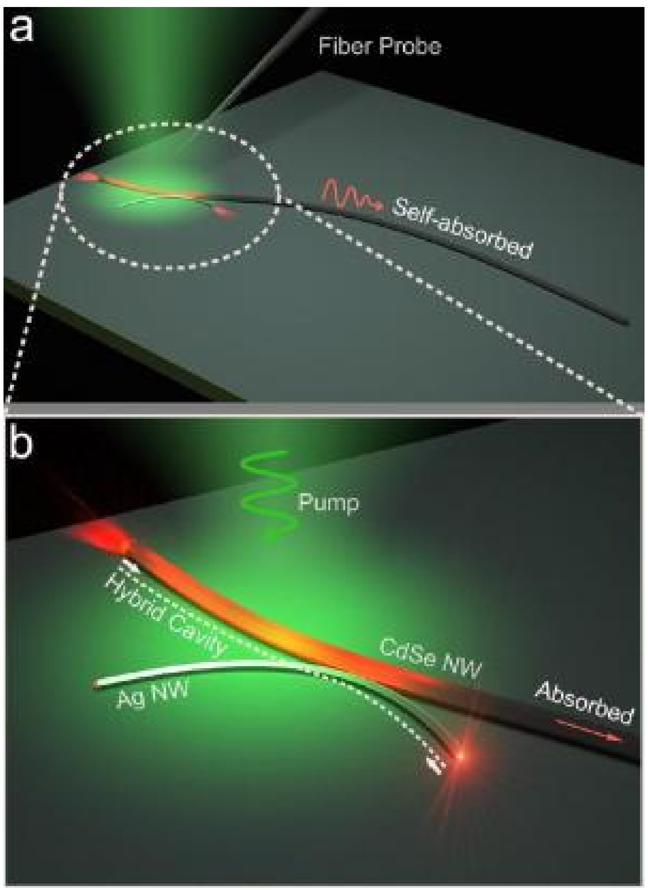

The hybrid photon-plasmon nanowire laser is composed of a Ag nanowire and a CdSe nanowire coupled into an X-shape. This type of coupling enables the photonic and plasmonic modes to be separated, which gives the hybrid laser advantageous features. Credit: Wu, et al. ©2013 American Chemical Society

Recently, researchers have been developing a new type of laser that combines photons and plasmons (electron density oscillations) into a single radiation-emitting device with unique properties. In particular, nanoscale photon-plasmon lasers can emit light that is more tightly confined than the light emitted by lasers that use only photons.

"Compared to conventional photon lasers, the hybrid photon-plasmon nanowire laser offers two outstanding possibilities: the extremely thin laser beam (e.g., down to the size of a single molecule) and the ultrafast modulation (e.g., >THz repetition rate), both stemming from the longitudinally separable pure plasmon nanowire mode," Limin Tong, Professor at Zhejiang University in Hangzhou China, told *Phys.org*. "Owing to the above-mentioned merits, photon-plasmon lasers are potentially better for certain applications such as strong coupling of quantum nanoemitters, ultra-sensitivity optical sensing, and ultrafast-modulated coherent sources."

Tong is coauthor of a paper by Xiaoqin Wu, et al., published in a recent issue of *Nano Letters*. In this paper, the researchers, from Zhejiang University and Arizona State University, have addressed a limitation facing the photon-plasmon lasers that have been developed so far, which is that the photonic and plasmonic modes cannot be separated. Consequently, only the photonic component can be directly used, which limits potential applications. This problem arises from the way that the photon and plasmon waveguides are coupled, which is in the transverse direction, or perpendicular to the beam direction.

In the new study, the researchers have demonstrated that the photon and plasmon nanowire waveguides can be coupled in the longitudinal direction; that is, along the direction of the beams. This type of coupling makes it possible to spatially separate the plasmonic mode from the photonic mode, and to simultaneously use both modes.

Under excitation, strong luminous spots are observed at both ends of the hybrid cavity, with interference rings indicating strong spatial coherence of the light emitted. The output spot of the Ag nanowire is much smaller than that of the CdSe nanowire, indicating much tighter confinement of the plasmon radiation. Credit: Wu, et al. ©2013 American Chemical Society

In their demonstration, the researchers used a Ag nanowire as the plasmonic waveguide and a CdSe nanowire as the photonic waveguide. They side-coupled the shorter (11-µm-long) Ag nanowire to the longer (470-µm-long) CdSe nanowire, forming an X-shaped structure with an overlap length of about 1.1 µm.

When photons that are waveguided along the CdSe nanowire reach the joint area, some of the photon modes continue traveling down the CdSe nanowire, while others are coupled and converted into the plasmon modes of the Ag nanowire. When these plasmon modes reach the end of the Ag nanowire, they are reflected back through the Ag nanowire to the joint area. Here they are converted back into photon modes and continue traveling back through the CdSe nanowire. When they reach the end of the CdSe nanowire, they are reflected again, resulting in a constant recirculation of photon and plasmon modes that generates the lasing oscillation.

The advantages of ultratight confinement and ultrafast modulation offered by side-coupling a plasmonic nanowire waveguide to a photonic one enable the hybrid laser to provide very precise lasing, which could be delivered to very small areas such as quantum dots. Photon-plasmon lasers can also have applications for nanophotonic circuits, biosensing, and quantum information processing. The researchers plan to make further improvements to the laser in the future.

"One of our future plans is to introduce the ultrafast nonlinear effects of the plasmonic nanowire into the hybrid laser, and explore the possibility of ultrafast-modulation of the nanolaser, while offering a far-field-accessible pure plasmon cavity mode with sub-diffration-limited beam size," Tong said.

More information: Xiaoqin Wu, et al. "Hybrid Photon-Plasmon Nanowire Lasers." *Nano Letters*. DOI: 10.1021/nl403325j