Threshold Analysis in Plasmonic Nanolaser with Monolayer Semiconductor as Gain Medium

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Abstract: We have examined the lasing threshold requirements for optically pumped surface plasmon based nanolasers with 2D materials as active medium, which is an excellent research tool as an on-chip nanoscale light source.

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There are increasing demands on miniaturization of photonic components in order to achieve high performance photonic integrated networks for optical computing and communication systems [1]. However, it is still a challenge to realize such efficient on-chip ultracompact lasers that can generate extremely focused optical excitations on potentially ultrafast timescales with dimensions beyond the diffraction limit. Recently, a few remarkable nanolasers has been reported by employing plasmonic properties of metals [2,3], which achieved excellent optical confinement far below the scale of the vacuum wavelength using surface plasmon polaritons (SPPs) at metal-dielectric interfaces. Here, we theoretically demonstrate a direct bandgap and room temperature optically pumped nanophotonic integrated lasing device consisting of high-index nanowire and monolayer transition-metal dichalcogenide semiconductors flake on top of silver substrate. Using a fully vectorial three-dimensional finite-difference time-domain method, we optimized the design of such ultracompact nanolaser to achieve the reduced lasing threshold where practical applications are viable. The proposed on-chip device can directly generate coherent optical fields at the nanometer scale and offer great potentials lead to large scale integration of photonic and electronic functionalities, thus enabling unprecedented capabilities in a wide range of technologies from computing and communication [4] to sensing and detection [5].

Figure 1 illustrated the nanolaser topologies that we investigated, with monolayer semiconductor as gain medium. This device structure supports a hybrid mode which is a superposition of the waveguide mode in nanowire and the SPP mode at metal surface [3,6]. The waveguide was designed to maximize the field at the location of the monolayer MoS_2, to maximize the absorption efficiency. Assisted by large-scale parallel computing grid at Brookhaven National Laboratory, we calculated important parameters to help us determine the lasing threshold of this device, which is an important figure of merit as it governs the minimum power consumption that is necessary for lasing operation. We can obtain the steady state solution of the coupled rate equations that shows the relationship between pumping rate R and photon densities P [7]. With a few optimization procedures, we can reach a lasing threshold of 100nW at room temperature.

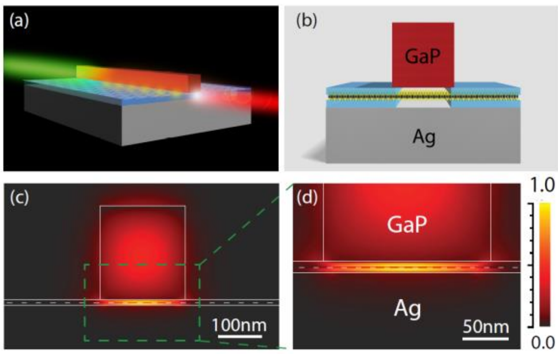

Fig. 1: (a) Structure of the proposed nanolaser using monolayer semiconductors as active medium. (b) The cross-section view of device structure, where the monolayer semiconductors is embedded in a low-permittivity spacer layer. (c) The hybrid mode profile. (d) The enlarged area for a clear demonstration of the gap mode with the dash line as the monolayer semiconductor material.

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