

Ultra-Narrow Linewidth Blue Plasmonic Single Mode Nanolasing from MBE-Grown GaN Nanowires with Embedded InGaN Quantum Wells

Talgat Shugabaev,^{ab} Ivan A. Melnichenko,^{ac} Alexey Kuznetsov,^{ad} Vera V. Lendyashova,^{ab} Pavel Bulkin,^e Demid A. Kirilenko,^b Alena Y. Gagarina,^f Anton A. Kharchenko,^a Igor V. Shtrom,^g Dmitriy A. Kozodaev,^h Natalia V. Kryzhanovskaya,^c Rodion R. Reznik,^{ab} Alexey D. Bolshakov,^{ad} George E. Cirlin,^{abg} and Vladislav O. Gridchin^{*abg}

^a Alferov University, St. Petersburg 194021, Russia

^b St. Petersburg State University, St. Petersburg 199034, Russia.

^c International Laboratory of Quantum Optoelectronics, National Research University Higher School of Economics, St. Petersburg 190008, Russia

^d Moscow Center for Advanced Studies, Moscow 123592, Russia

^e LPICM, UMR7647 CNRS Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau 91128, France

^f Department of microelectronic, Saint Petersburg Electrotechnical University «LETI», St. Petersburg 197022, Russia

^g Institute for Analytical Instrumentation RAS, St. Petersburg 190103, Russia

^h NT-MDT BV, Apeldoorn 7335, The Netherlands

*Corresponding author: gridchin@spbau.ru

Macro-photoluminescence measurements

Photoluminescence (PL) was excited using a He-Cd laser operating at a wavelength of 325 nm. The diameter of the focused laser spot on the sample was calculated based on the beam divergence of the laser and the focal length of the focusing lens, yielding a spot size of 125 μm at the $1/e^2$ intensity level. The total optical power incident on the sample was measured using a Thorlabs power meter and amounted to 11.3 mW, corresponding to an average excitation power density of approximately 91 W/cm^2 . The PL signal was collected and directed into a SOL instruments MS 5204i monochromator equipped with a diffraction grating of 1200 grooves/mm. Detection was performed using a single-channel silicon photodetector in combination with synchronous (lock-in) amplification. Measurements were carried out on an array of nanowires (NWs), with the excitation area encompassing a large number of individual nanostructures. Therefore, the recorded PL spectra represent ensemble-averaged optical properties of the sample. The measurements were performed at room temperature.

Micro-photoluminescence measurements

Figure S1 presents the micro-PL spectra of the plasmonic nanolaser measured at the minimum pump powers achievable in our optical system.

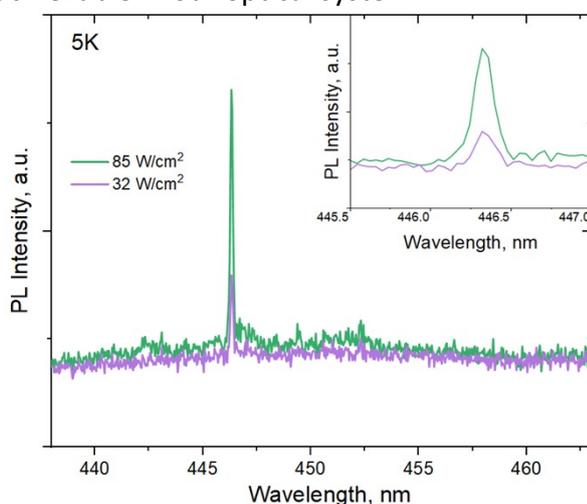


Fig. S1. PL spectra of the nanowire-based plasmonic nanolaser measured under minimal optical pumping at 5 K.

The presence of a narrow spectral line (FWHM < 0.14 nm) even at these low pump powers indicates that the lasing threshold at 5 K is below 32 W/cm².

Figure S2 shows micro-PL spectra of a single nanowire on a non-plasmonic bare Si substrate at various excitation powers. The measurements were performed using the same optical setup and excitation conditions as those for the plasmonic nanowires. As shown in Fig. S2, there are no sharp intense PL lines, which can be attributed to laser emission. Notably, a detectable PL signal from the nanowire on the Si substrate appears only at excitation powers of 955 W/cm². In contrast, clear signatures of laser emission in plasmonic nanowires are already observed at significantly lower excitation (32 W/cm² at 5 K, see Fig. 4 in the manuscript).

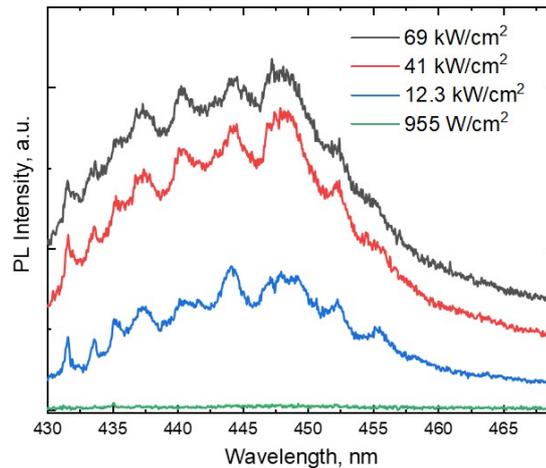


Fig. S2. PL spectra of a single InGaN/GaN nanowire on Si substrate recorded as a function of optical pumping at 5K.

Modeling

The surface plasmon-polariton (SPP) mode for the NW/AIO_x/Ag system and the corresponding dispersion curve were calculated using the finite-difference frequency-domain (FDFD) method in Ansys Lumerical software. For the simulations a non-uniform rectangular grid was used with a maximum spatial step of 0.6 nm. The boundary conditions had to absorb all incident power thus the perfectly-matched-layer (PML) was set at all boundaries (see fig. S3). Dispersion relation of SPP mode calculation was provided in the range of 390-800 nm. The optical constants for GaN, InGaN, AIO_x, Ag were taken from [1–4].

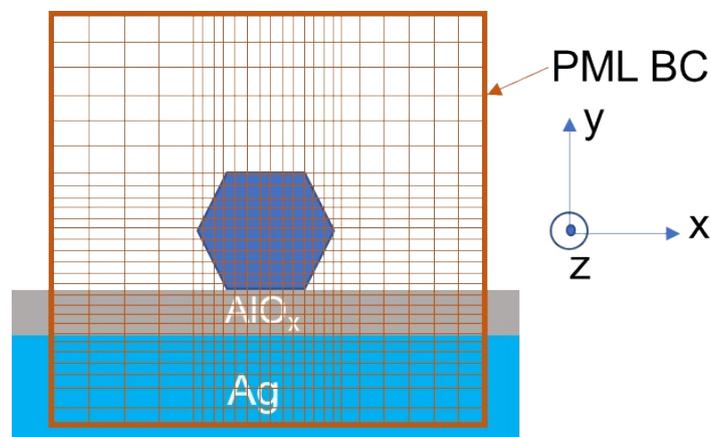


Fig. S3. Schematic for numerical simulation of SPP mode and the corresponding dispersion curve

To demonstrate how a hybrid heterostructure enhance photon-exciton coupling Purcell factor (F_p) calculation was provided via finite-difference time-domain (FDTD) method in Ansys Lumerical software. Single core-shell InGaN/GaN NW was simulated in full agreement with geometry evaluated via SEM and TEM results (see Fig.2). Nanowire was simulated as an equilateral hexagonal prism where outer diameter of circumscribed circle was 64 nm (GaN shell), diameter of the inner hexagonal insert which simulated the InGaN core was 48 nm. Length of GaN and InGaN hexagonal prisms was 1600 nm (See schematic in fig. S4). To avoid artificial reflection from the boundaries the PML was set to every boundary. Spatial mesh step was 1 nm. The optical constants were used from [1–5] for GaN, InGaN, AlO_x , Ag and Si respectively. The dipole source which was placed under the NW was utilized to simulate the PL. Calculation was provided at a wavelength of 446.3 nm.

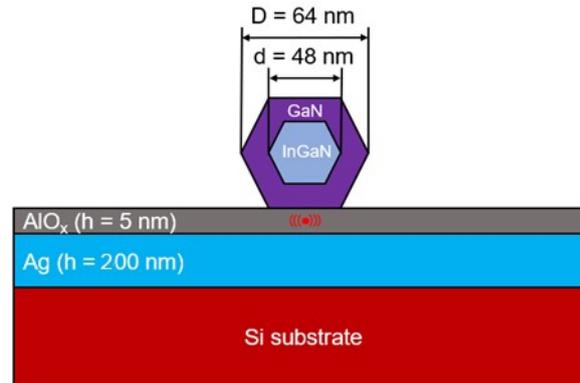


Fig. S4. Schematic of the single GaN/InGaN NW for numerical simulation of F_p

References

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