On-Chip Monolayer WSe_2 Microring Laser Operating at Room Temperature

CNF Project Number: 2524-17

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Primary CNF Tools Used: JEOL 9500, Logitech Orbis CMP, SÜSS MA6-BA6 contact aligner, Oxford 100 & 81 etchers

Abstract:

We demonstrate lasing at room temperature of monolayer WSe_2 integrated with a silicon nitride ring resonator. Signatures of lasing are shown by a 'kink' in the L-L plot and a linewidth narrowing of 30% when reaching threshold.

Summary of Research:

Monolayers of transition-metal dichalcogenides (TMDCs) are excellent materials to produce nanolasers since they are direct bandgap emitters and lack the need of lattice matching making them easy to integrate with planar devices. However, previously demonstrated TMDC nanolasers emit perpendicularly to the plane of their cavity into free space [1-4] and are thus challenging to integrate on chip. Integrated nanolasers are one of the key devices for fully integrated optical circuits, which require sources, modulators, and detectors interconnected with waveguides and electronics in a single chip. Modulation, detection and propagation of light have been demonstrated using TMDCs and other 2D materials. The waveguide coupled 2D material laser demonstrated here will ultimately enable photonic devices with sources, detectors, modulators, and sensors integrated in multiple photonic layers that can be monolithically integrated with electronics.

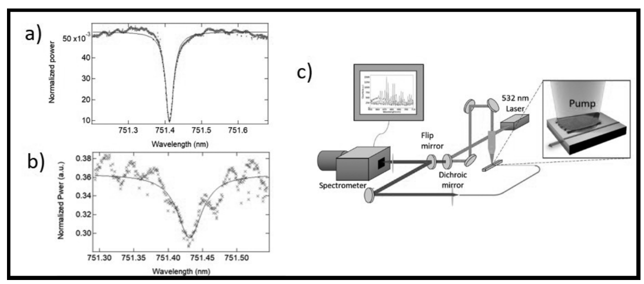

Figure 1: a) Ring resonace at 751.41nm with Q = 350,000-200,000. b) Ring resonance after monolayer transfer with Q = 95,000. c) Experimental setup to pump from the top and collect the chip's output from the side.

We demonstrate lasing from a monolayer tungsten diselenide (WSe_2) monolithically integrated with a high Q, chipscale silicon nitride microring resonator. This integration enables efficient light emission coupled to an on-chip waveguide. The device consists of a silicon nitride microring resonator with a radius of 13 µm coupled to a Mach-Zehnder Interferometer (MZI). We use the MZI to decrease the number of resonant modes since the gain threshold for lasing increases proportionally with the number of resonant modes of the cavity. Depending on the length of the MZI arms, resonances of the ring can be suppressed.

Our device is designed to suppress every other resonance of the ring, increasing its Free Spectral Range (FSR) by a factor of two. The width and thickness of the waveguide are 0.5 µm and 0.3 µm, respectively. The ring and bus waveguide are separated by a gap of 0.35 µm. Mechanically exfoliated WSe_2 is transferred using a PDMS-based all dry transfer technique [5] and placed on top of the microring resonator. Before the monolayer is transferred, the microring has an intrinsic *Q* of 350,000 (Figure 1a). After the monolayer transfer the intrinsic quality factor of the ring is 95,000 (Figure 1b) showing a strong interaction of the ring with the monolayer.

We fabricate the silicon nitride microring resonator by depositing 300 nm of silicon nitride via low-pressure chemical vapor deposition (LPCVD) on 4 µm of oxide thermally grown on a silicon wafer. The ring and bus waveguide are patterned with electron-beam lithography. A fill pattern that serves as a chemical mechanical polishing (CMP) stop layer is written with contact lithography. The nitride is etched in an inductively coupled plasma reactive ion etcher (ICP-RIE) using a CHF_3/O_2 chemistry. The device is clad with 1 µm of silicon dioxide via plasma enhanced chemical vapor deposition (PECVD). We polish the upper cladding down to a thickness of 0 to 20 nm using CMP to increase the interaction between the optical field in the resonator and the WSe_2 monolayer. The smooth surface after the CMP step also improves the adhesion of the WSe_2 flake.

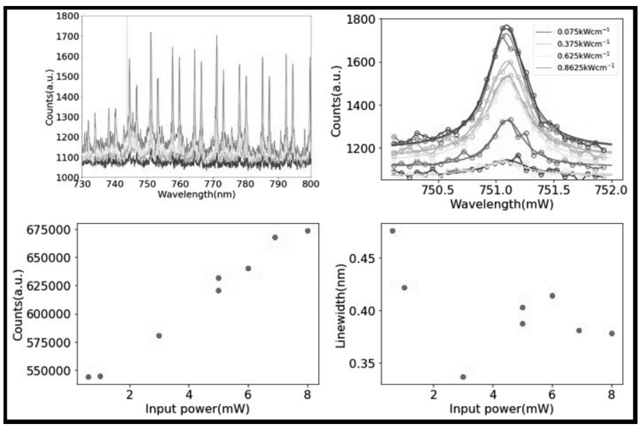

Figure 2: a) Spectrum for increasing input power. b) Lorentzian function fitting for a peak at 751.05 nm at different input powers. c) L-L plot showing a 'kink' between 1 mW and 3 mW of input power. d) Linewidth vs input power plot showing linewidth narrowing between 1 mW and 3 mW of input power.

We demonstrate optically pumped lasing emitted at a central wavelength of 751.05 nm by a monolayer of WSe_2. We focus the pump laser (CW Ti:Sapphire at 701 nm) emission that is coupled from the ring to the bus waveguide with a lensed optical fiber at the output of the chip. The collected emission is measured with a spectrophotometer (Figure 1c). The collected spectra (Figure 2a) show the expected WSe_2 broad PL spectrum centered at ~ 749 nm with peaks that match the ring resonances. All the measurements were done at a room temperature of 22°C.

The laser emission is identified by the behavior of the 'light-light' or L-L curve and the linewidth narrowing of particular peaks. We fitted a Lorentzian line shape to the individual peaks (Figure 2b) to obtain the FWHM values and output intensity values. The plot of the output light intensity (defined as the integrated area under the peak) vs. the input power in Figure 2c shows a 'kink' between 1 mW and 3 mW. For the same range of input power, the input vs. linewidth plot in Figure 2d shows progressive narrowing from 0.48 nm to 0.38 nm. The linewidth narrows by 30%. Linewidth narrowing indicates a laser like behavior of the emission coupled to the ring and later to the bus waveguide.

Conclusions and Future Steps:

In conclusion, our device demonstrated the possibility to integrate the photoluminescence of monolayer TMDCs and produce integrated laser emission at room temperature enabling a lasing platform that is scalable to arrays of on-chip lasers. Since integrated modulation and detection can also be achieved with 2D materials, our integrated laser opens the possibility to a fully integrated and complete optical circuit using the properties of 2D materials.

References:

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