Fabrication of Nanophotonic Optical Cavity Device from Inverse Design

CNF Project Number: 2126-12

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Primary Source(s) of Research Funding: National Science Foundation (ECCS-1839196)

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Primary CNF Tools Used: AJA sputter deposition, OEM Endeavor AlN sputtering system, JEOL 9500, JEOL 6300, PT770 etcher, AJA ion mill, P10 profilometer, P-7 profilometer, GCA 5x stepper

Abstract:

On-demand polarized single-photons are essential in realizing many photon-based quantum communication protocols [1]. We developed and fabricated a nanophotonic cavity device from aluminum nitride (AlN) whose structure was calculated from an inverse design method. The structure serves as a platform for enhancing the collection of single photons from isolated defects hosted in hexagonal boron nitride (h-BN). We present an update on our work-in-progress on the fabrication of the device.

Summary of Research:

Hexagonal boron nitride is an interesting 2D material due to bright optically active defects hosted within and to the possibilities of integrating with other 2D materials [2]. Researchers have been able to create isolated defects by methods such as ion implantation with carbon [3]. The defects are stable under room temperature and have zero-phonon line fluorescence at 585 nm [4]. People have been able to create or find isolated these defects. The combination of emission brightness and the capability of isolating them makes h-BN defects promising candidates as single-photon sources. In this project, we aim to fabricate an inverse design nanophotonic cavity structure and characterize its capability of enhancing photon emissions. The cavity structure further enhances the emission of h-BN defects placed on them due to the Purcell effect and modifies the emission angle of these defects so one can more efficiently collect the photons [5].

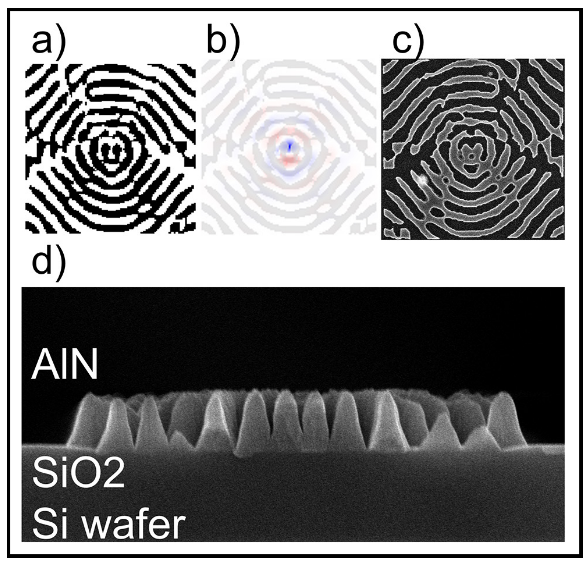

Figure 1: a) The target device structure from inverse design. Black indicates substrate and white air. b) The field mode profile at 600 nm resonance. Note that most of the energy is concentrated at the central region. c) An SEM image of the Cr hard mask before the final AlN etch. d) An SEM image of the cross section of the device.

We fabricated the current generation devices on Si wafers, which allows us to cleave the sample and inspect the cross section. The devices are made from AlN sputtered by the OEM Endeaver M1 AlN sputter system. The structure is patterned with the JEOL 9500 electron beam lithography system and is subsequently etched with a Cl_2 plasma reactive ion etching process in the PT770 etcher.

Figure 1 shows (a) the design target structure and (b) the field profile at resonance at 600 nm. Figure 1c shows the mask pattern prior to AlN etching, indicating a good fidelity of patterning from design structure. However, as seen in Figure 1d, the AlN etching step is problematic due to high aspect ratio (15:1) and results in slanted sidewalls and incomplete etching of the interior of the pattern.

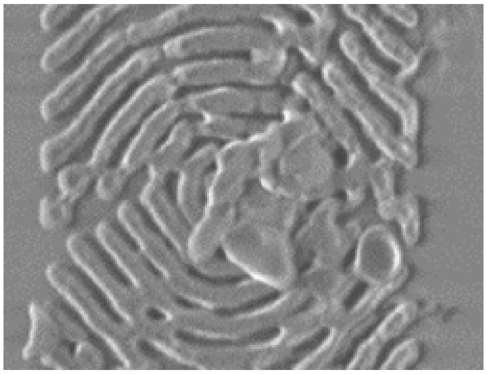

Figure 2: A top-down SEM image of a few h-BN nanoflakes on top of the AlN device.

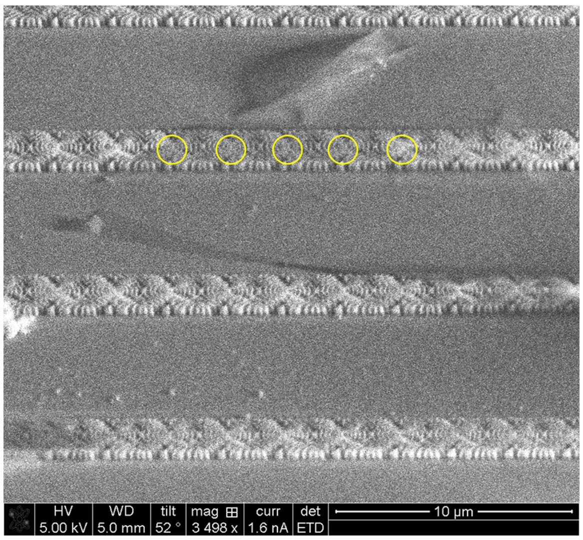

Figure 3: An SEM image of an exfoliated h-BN flake over a few cavity devices. The circles indicate the regions for focused ion beam milling to create defects.

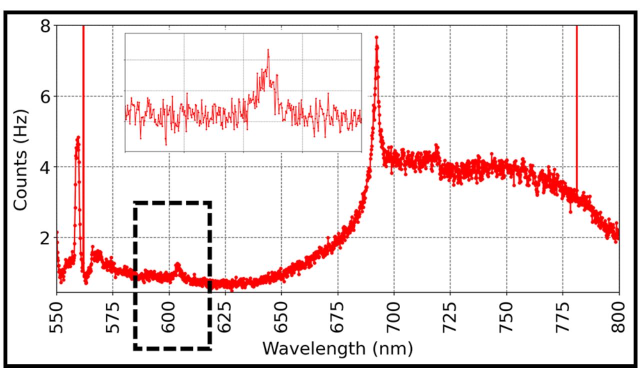

Figure 4: A spectrum taken at the central region of the cavity device. The insert magnifies around the spectral feature around 604 nm.

While we continue to improve the fabrication process, we started testing strategies of placing single emitting h-BN defects on the cavity structure. Figure 2 shows our early attempts of placing h-BN nanoflakes on top of the device through drop-casting sufficiently many of them on a chip containing many of such cavity devices. We also tried placing an exfoliated h-BN flake over the device and creating defects by lightly milling the flake with focused ion beam (Figure 3). Unfortunately, the early attempts did not result in single emitters in the range of the enhancement region. However, we observed an enhancement of the background fluorescence near the device center at 604 nm, which likely comes from the device as shown in Figure 4.

Future Work:

We are exploring ways of creating and positioning single defects in h-BN with better repeatability. We also pursue a different design which optimizes upward photon flux which may achieve a higher photon collection rate.

Acknowledgements:

We would like to thank members of the Rodriguez Group on the discussion on and their designs of the nanophotonic cavity structures.

References:

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