Properties of Isolated Defects in Hexagonal Boron Nitride

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Primary CNF Tools Used: Scanning electron microscope, contact aligner, profilometer

Abstract:

We investigate the optical properties of defect-based single photon sources in hexagonal boron nitride (hBN) produced via solvent exfoliation (S-hBN) and mechanical exfoliation (M-hBN). Single defects found in S-hBN exhibit spectrally narrow zero-phonon emission and an absorption and emission dipole that may or may not be aligned parallel to one another. Defects found in wide area (> 50 × 50 μm) M-hBN multilayer flakes possess a broader zero phonon line and are less bright than the defects in S-hBN flakes. To study M-hBN, we develop a reliable method for mechanically exfoliating bulk h-BN crystals and precisely transferring it to a Si/SiO_2 substrate. Optically stable defects are subsequently created in the flake via an argon plasma etch combined with a thermal annealing treatment. The investigated defects may be in regions of the flake that is in contact with the substrate or, alternatively, in regions that are suspended over pre-patterned holes. Defects in the suspended region are not influenced by the substrate and may potentially couple to the mechanical modes of the resulting hBN drumhead.

Summary of Research:

Point defects in wide bandgap semiconductors exhibit quantum emission and have been identified as candidates for applications in quantum optics, precision sensing, and quantum information technologies [1]. Defects have been optically isolated in three-dimensional materials such as diamond, SiC, ZnO, and GaN, and more recently in two-dimensional materials such as transition metal dichalcogenides (TMDs) and hexagonal boron nitride (hBN) [2-6]. The defects in hBN exhibit ultrabright and polarized single photon emission. However, these single photon sources also exhibit significant defect-to-defect variation, making the comparison of experimental results with theoretical predictions difficult. In this work we compare the optical properties of single photon sources in hBN samples produced via solvent exfoliation (S-hBN) and mechanical exfoliation (M-hBN).

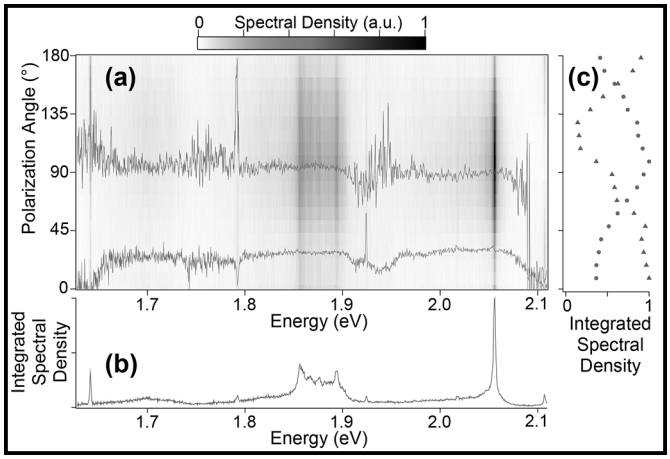

Figure 1: Spectrally resolved polarization measurements of an isolated defect in S-hBN revealing that the absorption and emission dipoles are misaligned.

Figure 1 shows a set of spectrally resolved polarization measurements made on a single defect in S-hBN. Figure 1a is a two-dimensional image plot revealing the fluorescence intensity of light emitted at a particular polarization angle. It was obtained by rotating a polarization analyzer in the collection path and collecting an emission spectrum at each orientation of the polarization analyzer. By vertically integrating the columns in the plot, we recover the unpolarized emission spectrum, shown in Figure 1b. In the unpolarized emission spectrum, a narrow zero phonon line (ZPL) and phonon sideband (PSB) are evident at ~ 2.05 eV and ~ 1.88 eV, respectively. By horizontally integrating the

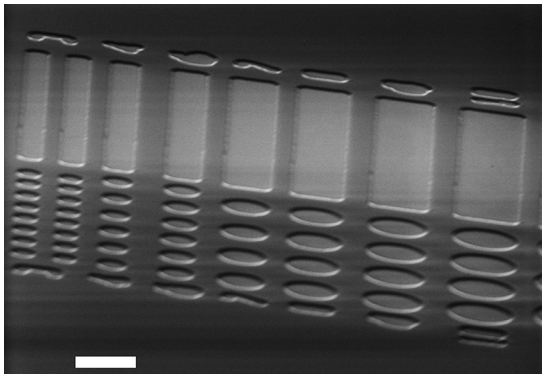

Figure 2: Scanning electron microscope image of holes and trenches fabricated onto a Si/SiO_2 substrate. The scale bar is 10 μm.

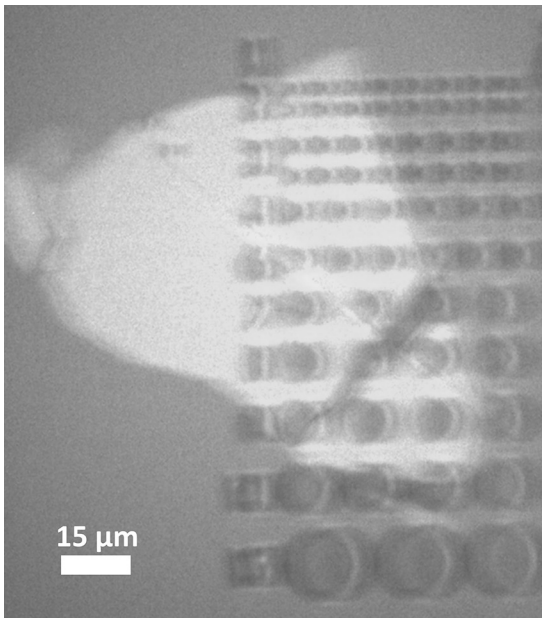

Figure 3: Optical microscope image of an hBN flake transferred to a region of the substrate containing holes and trenches.

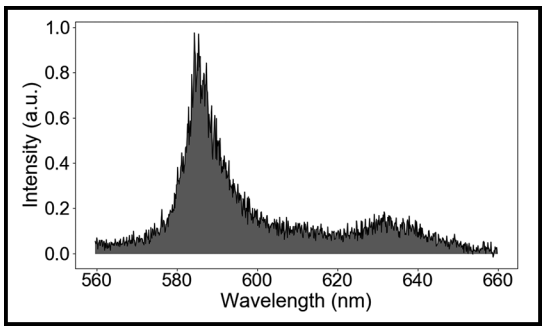

Figure 4: Emission spectrum of a single defect in M-hBN.

rows in Figure 1a we recover the spectrally averaged emission polarization profile (circles, Figure 1c). For comparison, the spectrally averaged excitation polarization profile is included as well (triangles, Figure 1c). Note that the absorption and emission dipoles are misaligned. This is confirmed by the spectrally resolved orientation of the emission and absorption dipoles, shown as the upper and lower traces, respectively, in Figure 1a.

To investigate defects in M-hBN, we developed a process of mechanically exfoliating bulk hBN crystals and precisely transferring them onto pre-patterned Si/SiO_2 substrates. Figure 2 is a scanning electron microscopy image of one such pre-patterned substrates revealing holes and trenches. Large area ($> 50 \times 50$ μm) M-hBN flakes may then be suspended over these holes (Figure 3). As-transferred M-hBN exhibits very low defect density, making it difficult to optically isolate individual defects. To increase the defect density, we argon etch as-transferred flakes and subsequently anneal the samples in nitrogen at 850°C for 30 minutes. After this sample treatment the defect density is enhanced and individual emitters maybe studied in suspended regions and in supported regions. Defects studied in suspended regions are not influenced by the substrate whereas defects in the supported regions may be influenced by charge traps in the underlying substrate.

Figure 4 is a room-temperature emission spectrum of a single defect in a suspended region of the M-hBN shown in Figure 3. Note that similar to S-hBN defects, this M-hBN defect also exhibits a broad ZPL and a PSB that is red-shifted from the ZPL by ~ 165 meV.

References:

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