Study of light emission in low-dimensional hexagonal boron nitride for photonic and optoelectronic applications

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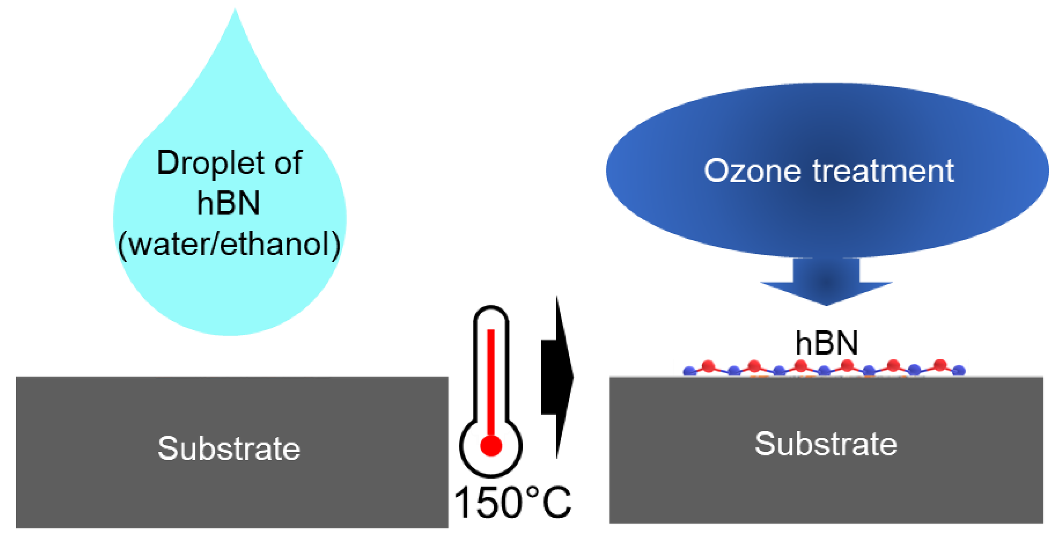
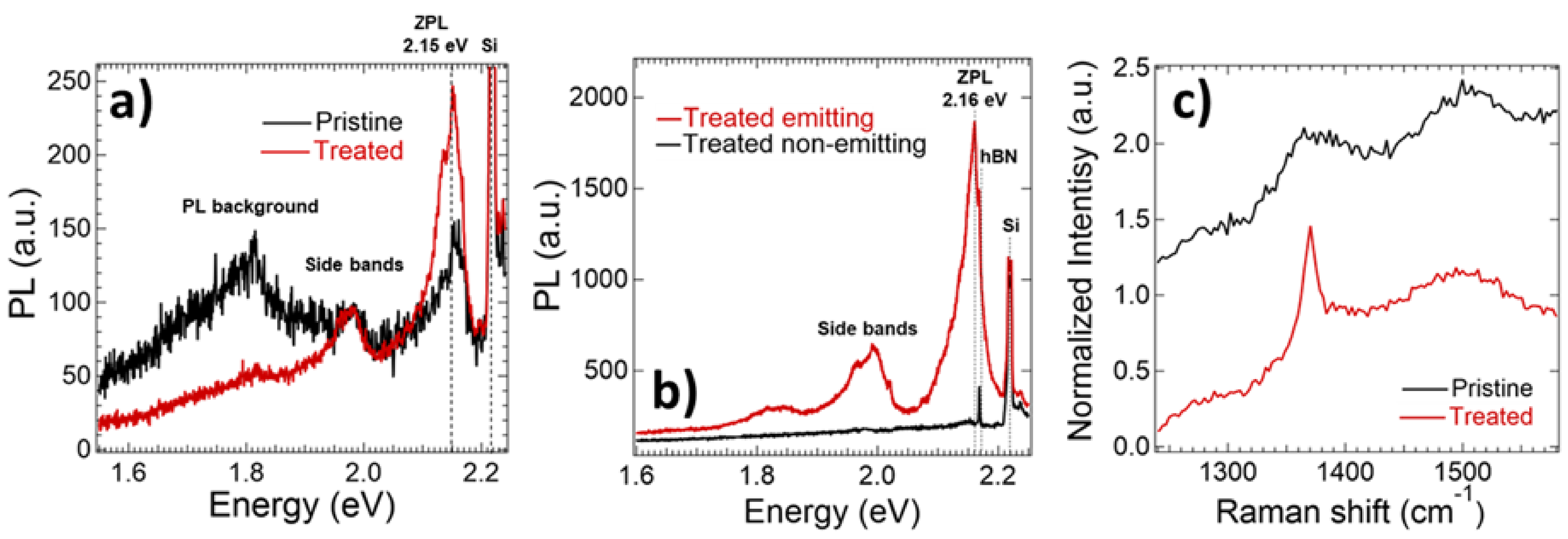
Abstract

Hexagonal boron nitride (hBN) is a wide-bandgap van der Walls material owing outstanding properties for many different applications at nanoscale. Especially, relatively newly discovered atomic colour defects in the crystal lattice with broad range of emission energies from ultraviolet to near infrared confined within their bandgap have attracted intensive attention in quantum information and communication technologies. Here, we study optical properties of these colour defects in few-layer hBN nanosheets exfoliated on semiconducting and metallic substrates by a set of micro-spectroscopy techniques. Thickness of hBN nanosheets ranging from 1 to 5 monolayers was determined by micro-Raman spectroscopy with a thickness dependent shift of the high frequency in-plane E_{2g} phonon mode. Emitters were engineered by thermal processes and quality of light emission was highly improved by ozone surface treatment. Micro-localized colour defects show bright (≈1 MHz) and stable room temperature light emission with zero-phonon line central energy varying from 1.56 eV to 2.27 eV and maxima at 2.16 eV. To deeper understand of emission properties, we applied far-field simulations as function of hBN thickness and underlying substrates. In agreement with experimental results, collected emission differs depending on the substrate used with the highest efficiency on Si, emission losses on SiO_2/Si and thin metal substrates with additional deterioration of emission properties and photoluminescence quenching. Despite of the lowest emission brightness of monolayers, emission properties are comparable to thicker crystals proving their high quality. It follows, that structural quality of hBN crystal through its surface and interface interactions plays an important role to enhance light emission properties. Furthermore, after optimization of single photon emission, the final ambitious step will be coupling of proposed light emitters into scalable quantum photonic circuits.

Preparation

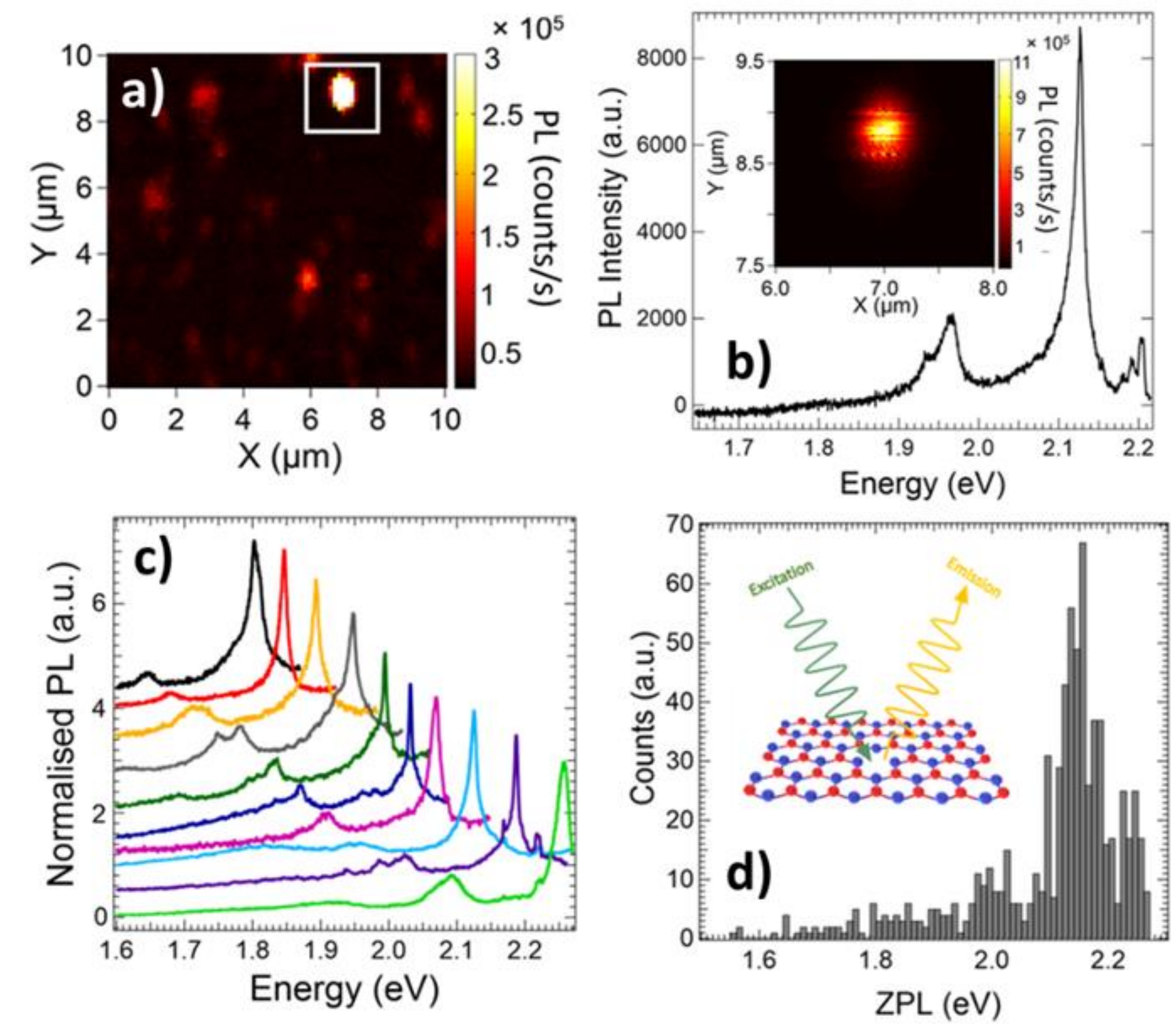


Preparation of light emitting nanosheets including drop casting of water/ethanol hBN solution on heated substrate followed by ozone post treatment to remove organic residues and improve emission purity.



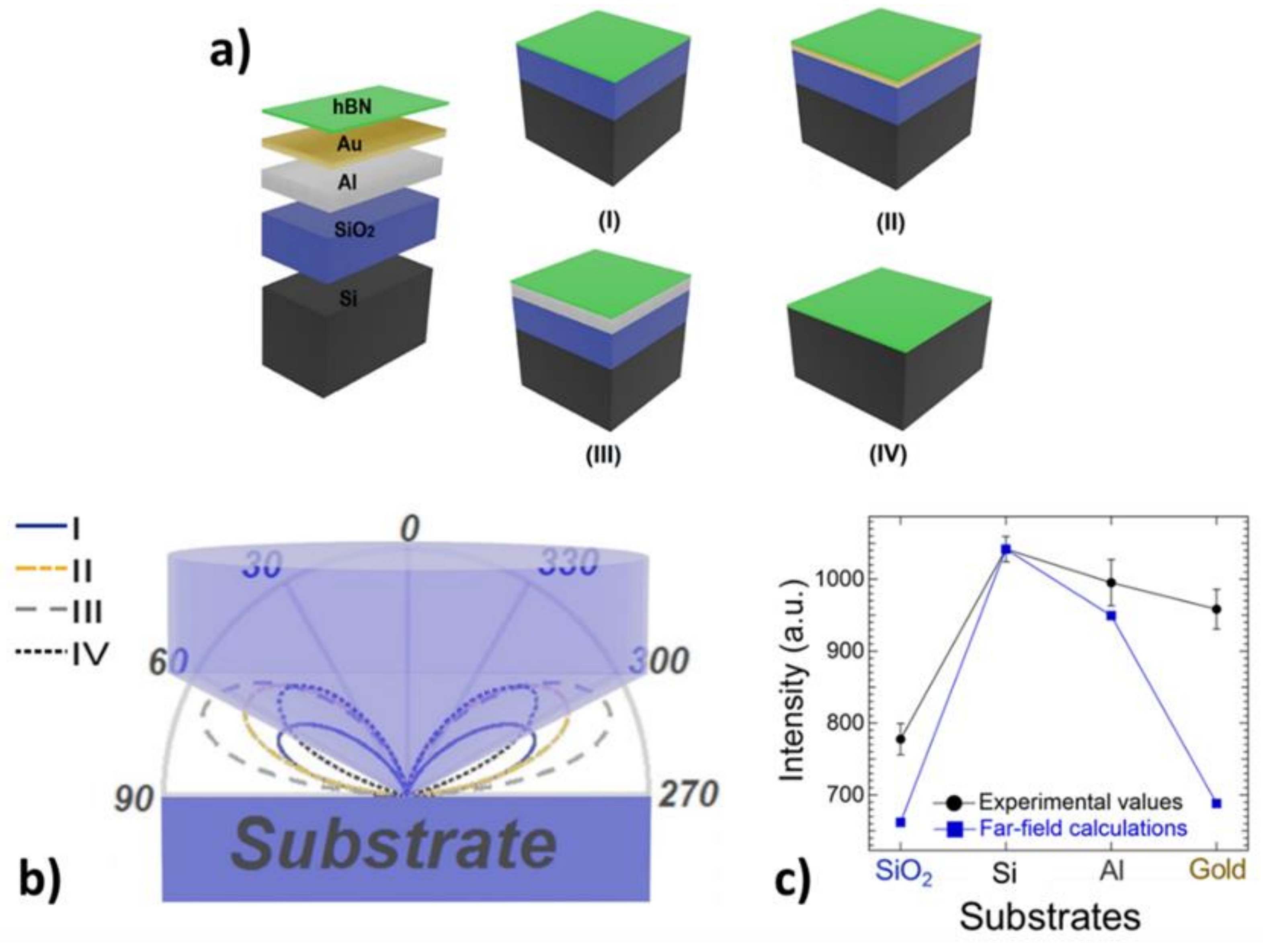
(a) PL spectra comparison of a micro-localized light emitter in pristine and treated hBN. (b) PL of treated hBN with and without presence of light emittter. (C) Comparison of Raman spectra for pristine and treated hBN showing improvement of crystal quality.

Emission properties



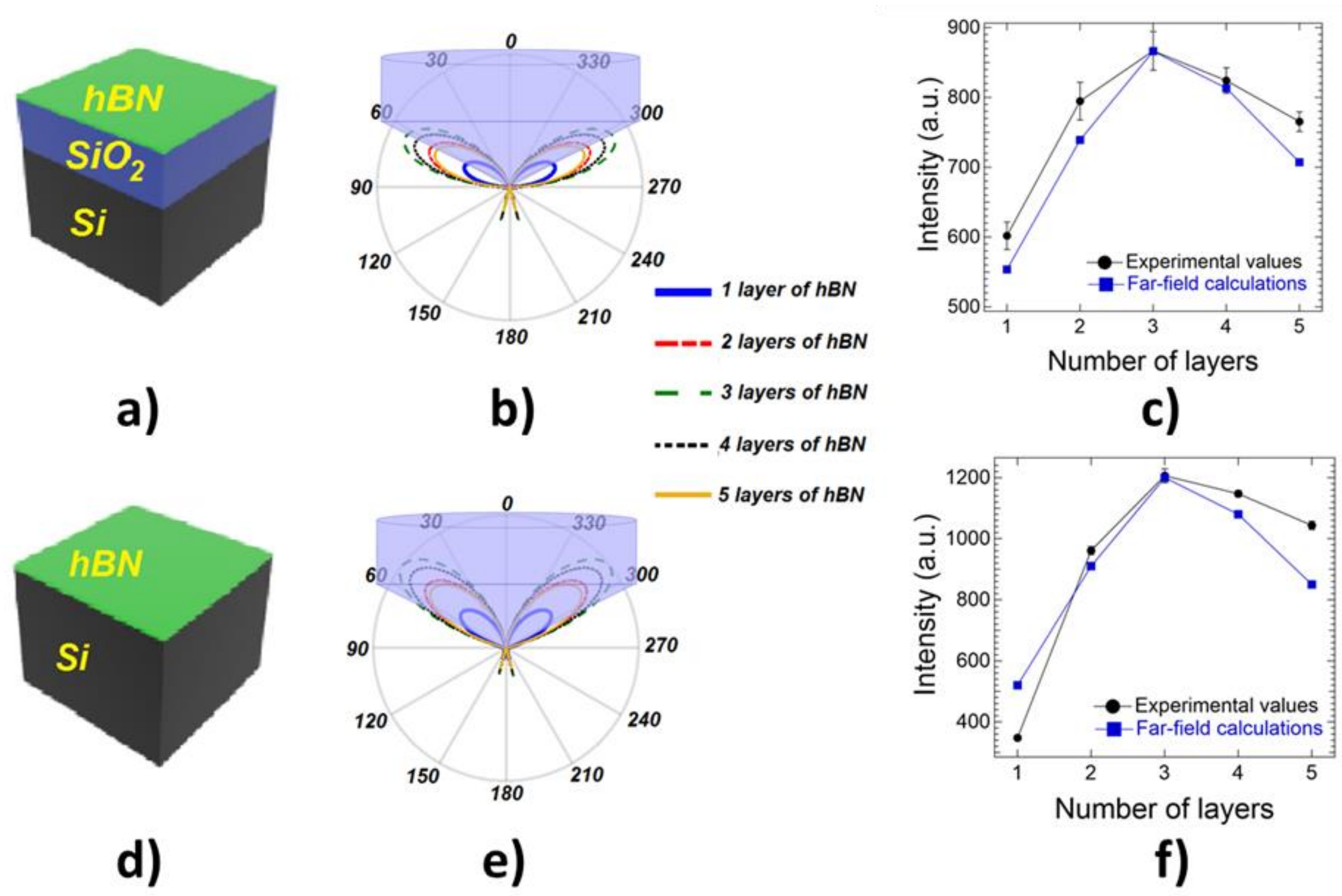
(a) PL map of micro-localized emission in hBN. (b) PL map and spectra corresponding to zoom of the highlighted point defect (inset). (c) PL spectra of several point emitters with zero phonon line (ZPL) and phonon side band emission energy across the visible spectrum. (d) Histogram of all monitored ZPL energies with maxima at 2.16 eV.

Emission on different substrates



(a) Schematic representation of different substrates used for hBN exfoliation: (I) SiO_2/Si, (II) Au/SiO_2/Si, (III) Al/SiO_2/Si and (IV) Si. (b) The angular distribution (NA=0.9) of the radiated intensity from hBN nanosheets in the far-field corresponding to the represented structures in (a). (c) Illustration of the maximum values of the radiated intensity as function of different substrates for calculated and experimental values.

Thickness dependent emission



(a),(d) schematic of two commercial substrates used for exfoliation and corresponding (b),(e) the angular distributions of the radiated intensity in the far-field as a function of the hBN thickness. (c) and (f) illustrate the maximum values of the radiated intensity versus number of the hBN layers for calculated and experimental values on substrate (a) and (d) respectively.

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