

Electron-beam-induced carbon doping of hexagonal boron nitride

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Hexagonal boron nitride (hBN) is a two-dimensional material structurally similar to graphene but distinguished by its wide bandgap and alternating boron and nitrogen atoms instead of carbon. Recently, hBN has gained significant interest because some of its defects have been shown to serve as single-photon emitters at room temperature. The most promising defects for quantum emitters are single-atom vacancies and substitutional atoms, with defects containing carbon impurities showing particular promise for quantum technology applications [1]. This study investigates carbon doping of hBN via electron-beam-induced deposition. The high-energy electrons used for imaging in a scanning transmission electron microscope are used to create vacancies in the hBN lattice. At the same time, methane (CH₄) is introduced into the column, where the electron beam dissociates the molecules, releasing carbon atoms that migrate into the vacancies to form carbon-based structures. Time-resolved image sequences at various pressures (6^{-9} - 1^{-7} Torr) are recorded to monitor this process. These series are used to determine pore growth rates and image carbon structures in the lattice. Electron energy-loss spectroscopy (EELS) is used to verify the elemental composition. The results show that boron and nitrogen atoms are gradually replaced by carbon. Surprisingly, increased methane concentration slows nanopore growth during the experiment and leads to a new type of defect—triangular carbon-terminated pores. Our experiments show that these pores are induced by hydrogen in the column.

[1] Mendelson, N., Chugh, D., Reimers, J.R. et al., *Nat. Mater.* **20**, 321–328 (2021).