Recent advances in gas-assisted electron and ion beam induced surface processing techniques

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Gas-assisted charged particle beam processing enables direct-write nanofabrication using electron and ion beams. Here I will review recent applications of these techniques with an emphasis on:

- electron and oxygen ion beam etching of diamond (Figure 1),[1,2]
- use of cryogenic techniques for electron beam induced etching of semiconductors and insulators (Figure 1),[3]
- use of high temperature techniques for electron beam induced deposition of high purity materials, [4]
- use of electron beams for material functionalization achieved by chemical alteration of the local surface electronic structure (Figure 2),[5]
- use of electron beams for characterization of surface-adsorbed gas molecules,[6] and
- the role of self-assembly in gas-mediated charged particle beam fabrication (Figure 3).[7]

The above applications will be used to highlight recent progress made in overcoming conventional limitations of electron and ion beam fabrication techniques, such as inadequate material purity, ion beam damage, and low throughput inherent to the sequential nature of direct-write techniques.

[1] Martin, A. A., Toth, M. & Aharonovich, I. Subtractive 3D Printing of Optically Active Diamond Structures. **Sci. Rep.** 4, 5022 (2014).
[2] A. A. Martin, S. Randolph, A. Botman, M. Toth & I. Aharonovich. Direct-write milling of diamond by a focused oxygen ion beam. (submitted).
[3] A. A. Martin & M. Toth. Cryogenic Electron Beam Induced Chemical Etching. **ACS Appl. Mater. Interfaces** 6, 18457–18460 (2014).
[4] Bishop, J., Lobo, C.J., Martin, A., Ford, M., Phillips, M. & Toth, M. Role of activated chemisorption in electron beam induced deposition. **Phys. Rev. Lett.** 109, 146103 (2012).
[5] Shanley, T., Martin, A. A., Aharonovich, I. & Toth, M. Localized chemical switching of the charge state of nitrogen-vacancy luminescence centers in diamond. **Appl. Phys. Lett.** 105, 063103 (2014).
[6] J. Cullen, A. Bahm, C. Lobo, M. Ford & M. Toth. Localized probing of gas molecule adsorption energies and desorption attempt frequencies. (submitted)
[7] Botman, A., Bahm, A., Randolph, S., Straw, M. & Toth, M. Spontaneous Growth of Gallium-Filled Mi-crocapillaries on Ion-Bombarded GaN. **Phys. Rev. Lett.** 111, 135503 (2013).

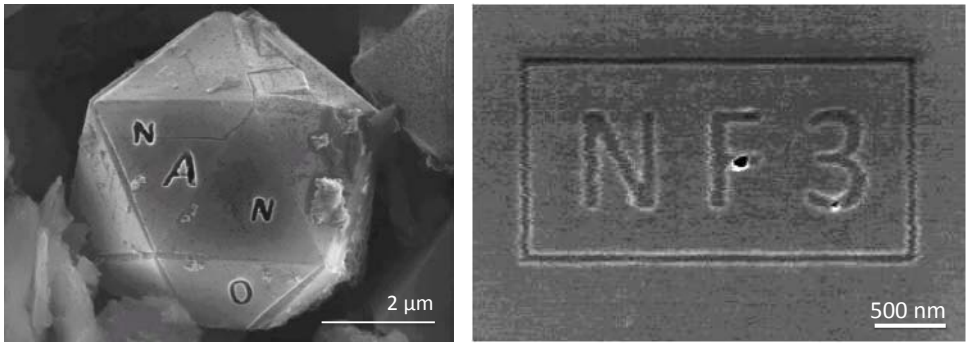

Figure 1: Etching: Patterns etched into diamond (left)[1] and silicon (right)[3] using H_2O as a room temperature etch precursor, and NF_3 as a cryogenic precursor gas.

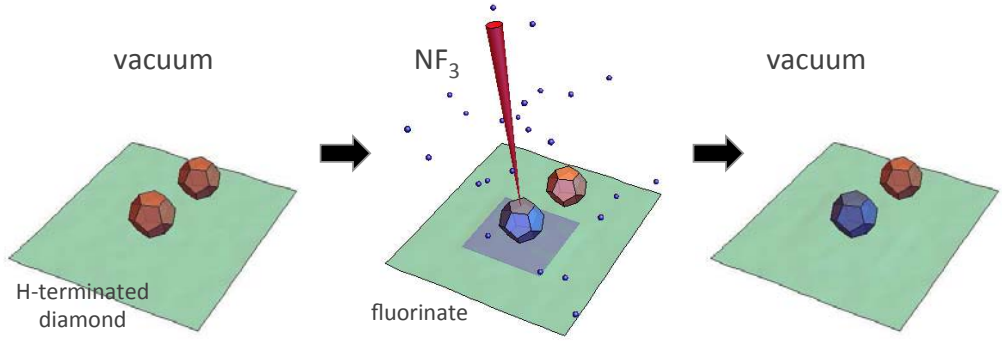

Figure 2: Surface functionalization: Schematic illustration of a direct-write process used to control the surface electronic structure and fluorescence properties of nanodiamonds by room temperature electron beam processing in a gaseous NF_3 environment.[5]

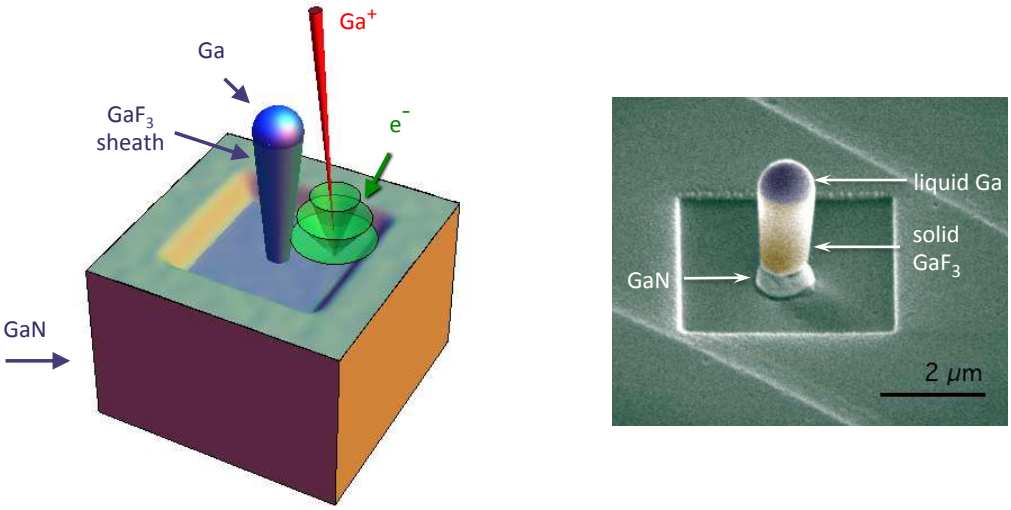

Figure 3: Self-assembly: Schematic illustration (left) and a false-color SEM image (right) of a pillar grown by Ga^+ ion beam bombardment of GaN in an XeF_2 environment.[7]