Invited poster

Focused Electron Beam Induced Etching - Advantages, Features & Limitations of FEBIE with Chlorine

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While electron beam induced deposition is widely applied for the deposition of noble metals, magnetic materials and dielectrics, the complimentary process of etching is less popular. This work provides a comprehensive insight on the mechanisms and challenges of etching processes with an electron beam. With exemplary semiconductor devices the usefulness of focused electron beam induced etching (FEBIE) for applications is demonstrated.

The focused beam of electrons cannot only be used for inducing the decomposition of precursor molecules leading to a deposition of solid material. The analogous process can be used to initiate a locally confined reaction of a material surface with an etch gas.[1] The electron induced removal of organic material with water[2] and of alumina particles by nitrosyl chloride[3] and of silicon dioxide[4] by XeF_2 has been demonstrated. However, for semiconductors the XeF_2 leads to - often undesirable - spontaneous etching. For modification of the semiconductors silicon and germanium we introduce a chlorine based process.

One of the challenges with etching is the deposition of carbon from residual gas, which is competing with the etch process. As the carbon layer may either delay etching or even totally mask the etched area, the etch process must be performed in a clean chamber under suitable beam parameters. We will describe the details of our custom-designed chamber cleaning system using ozone and ultraviolet light and will report on the cleaning efficiency of this system. For high etch rates with Si or Ge the chlorine-based etching should be performed at high beam current. Further recommendations for successful etching will be described.

Finally two exemplary applications of Chlorine-bases FEBIE will be described: As amorphous semiconductors are etched much faster than monocrystalline material (Fig.1), this process was employed to remove the Ga-contaminated surfaces of FIB-made cross-sections (Fig.2). Chlorine-based surface modification of Si or Ge nanostructures was employed to custom-tailor the electrical properties of nanowires (Fig.3, Fig.4) and transistor devices. This demonstrates that chlorine-based FEBIE is a well-controllable and contamination-free approach to modify nanomaterials.

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[1] Randolph, S.J., Fowlkes, J.D., Rack, P.D., Crit. Rev. Sol. State Mat. Sci. 31(3), 55 (2006)
[2] Miyazoe, H., Utke, I., Michler, J., Terashima, K. , APL 92 (4), 043124
[3] Bret,T., Afra,B., Becker,R., Hofmann,T, Edinger,K., Liang,T., Hoffmann,P. JVSTB 27 (6), 2727 (2009)
[44] Randolph, S.J., Fowlkes, J.D., Rack, P.D. , J.Appl. Phys. 98 (3), 034902 (2005)

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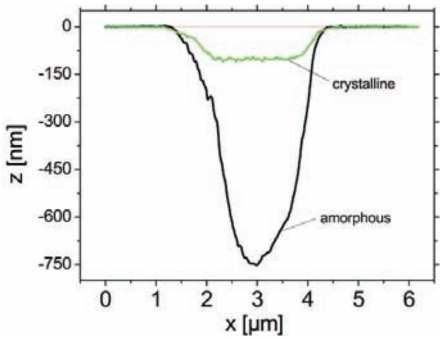

Fig. 1: Cross-section through different semiconductor substrates. Profiles were deduced from AFM analysis. An amorphous germanium film is etched up to 8 times faster than crystalline germanium. Both were treated for 10 minutes by 5 keV and 5 nA.

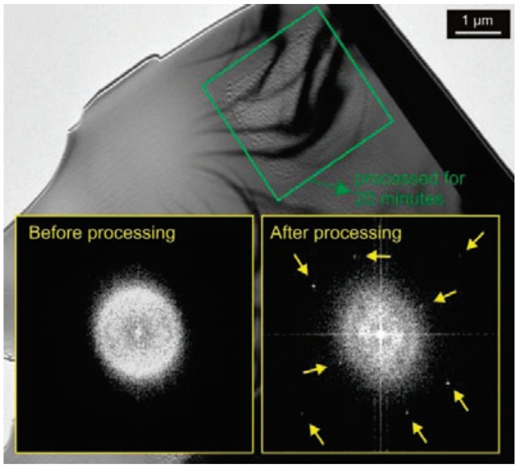

Fig. 2: TEM image of a FIB-prepared TEM lamella The green rectangle (3 × 3 µm²) shows the area that was post-processed solely by Cl_2-FEBIE. The two diffraction patterns illustrate the crystallinity of the processed area before and after Cl_2-FEBIE. The yellow arrows indicate the reflections which originate from the crystalline silicon structure of the TEM lamella.

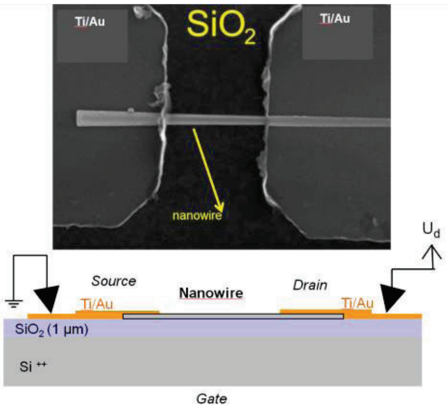

Figure 3. Measurement setup for the electrical characterization of a FEBIE-processed semiconductor nanowire. The top image shows a SEM image in top view. The bottom image depicts a schematic cross-section of the setup.

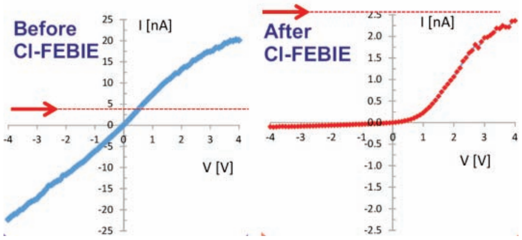

Figure 4. Electrical behavior of the Si-nanowire. The I-V-curve shows the electrical properties before and after FEBIE modification.