Focused Beam Induced Etching
Making the Right Choice between Ions and Electrons

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Gas assisted processing with a focused particle beam has become increasingly popular as direct-write lithography as it is a maskless and resistless nanostructuring method. Origins of this method trace back tothe emergence of focused ion beam tools where the purely physical removal of material in a locally confined scan field has been performed by ion sputtering with a focused beam. It has been shown, that both an ion beam as well as an electron beam can be used for locally confined etching. We present a comprehensive comparison of beam induced etching with both types of particle beam. The issue of the right choice – ions or electrons – will be addressed with regard to crystallinity, roughness, etch rate and other specifications of the desired structure. The removal rates for purely physical milling, ion induced etching and electron-induced etching will be compared for selected materials.

Focused ion beam milling is a physical sputter process, that can precisely remove material in a predesigned area, but faster removal rates can be achieved by gas assisted etching. Addition of an etch gas allows to chemically attack the material, remove volatile and to increases the removal rate tremendously. However, some materials experience spontaneous chemical etching. This was experienced with xenon difluoride (XeF2) and silicon (Fig. 1) which results in a poorly controllable process. It could be demonstrated that the same etch gas used for silicon dioxide facilitates a highly-controllable process as no spontaneous etching occurs. The acceleration in process speed by a factor 5 or more could be observed as shown in Fig.2. However, all FIB processes suffer from the amorphisation of the sample surface and by the implantation of gallium originating from the ion beam.

Latter effects can be avoided by electron beam induced etching. For a long time focused electron beam induced etching (FEBIE) has not been feasible due to (i) the contamination deposition blocking the access of the etch gas to the substrate and (ii) spontaneous etching by the commercially popular XeF2 (Fig. 3). In this work a highly reproducible etch process with an electron beam is reported using chlorine as etch gas. (Fig. 4). It could be shown that the crystallinity of samples is maintained with this process, which opens new ways to failure analysis on semiconductor devices. The optimum parameter set for a highly-controllable process to etch Si will be described..

For different applications such as the preparation of 3D samples, TEM-cross-sections and fabrication of prototype semiconductor devices the advantages and limitations of both approaches (electron – ion) will be compared..

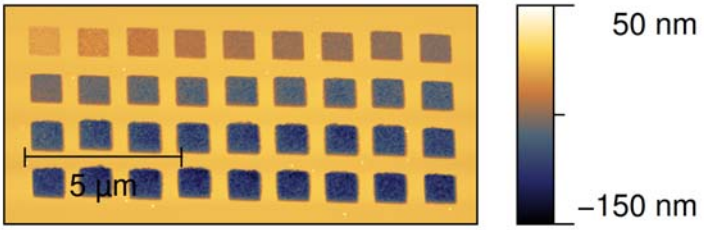

Fig.1 AFM image of Si etched with a FIB using XeF2 as etch gas.. All areas are sequentially exposed at 10 pA for 1s starting at the right bottom corner and progressing to the left top corner. The different depths are due to the progressing spontaneous etching once the native oxide film is removed from the Si surface.

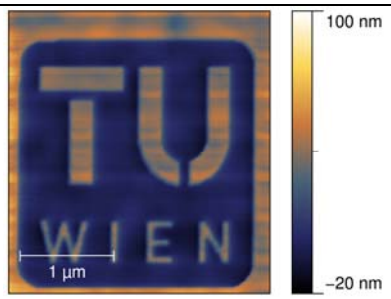

Fig. 2a FIB-milled logo in SiO2 without XeF2 addition

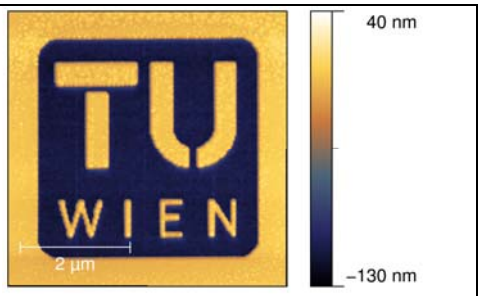

Fig. 2b FIB-milled logo in SiO2 with XeF2 addition

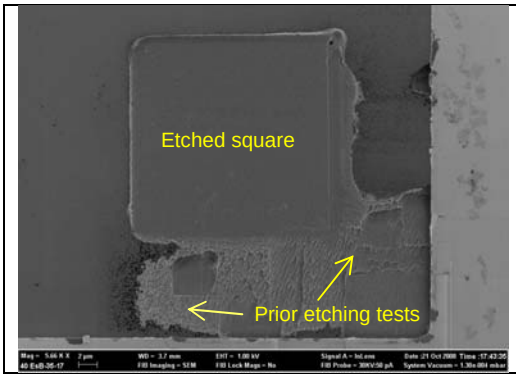

Fig. 4. Top view SEM image of etch pits fabricated on Si by etching with XeF2. Significant spontaneous etching was observed.

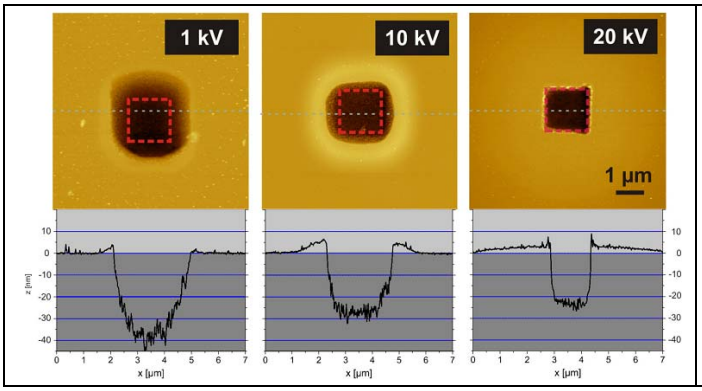

Fig. 4. AFM images and corresponding cross-sections of etch pits fabricated on Si by etching with chlorine using three different electron beam energies. (highlighted red squares = actual scanned area)