Fundamental focus beam-solid interactions and applications for rapid prototyping

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Focused electron, ion, and photon beams have demonstrated unparalleled potential for direct-write nanosynthesis and rapid prototyping. Fundamental focused beam-solid interactions will be discussed to evaluate the potential for each as a rapid prototyping tool. Combining the benefits of multiple beams (i.e. ion/electron and photon) for processing techniques, can enable expanded nanopatterning capabilities. In this work, several novel methods are discussed for direct-write nanoscale processing. These include laser-assisted focused electron and ion beam processing techniques (schematic shown in Fig. 1a), such as laser assisted focused electron beam induced deposition (LAEBID) and laser assisted focused ion beam induced etching (LAIBIE).

Several studies will also be discussed in which focused beams were used for rapid prototyping materials to reveal emergent properties by nanopatterning and defect engineering. First focused He^+ irradiation was used as an athermal activation for amorphous IGZO[1] (a transparent semiconductor). Controlling He^+ dose enables the tuning of charge density and a dose of 1×10^{14} He^+/cm^2 induces a change in charge density of 2.3×10^{12} cm^{-2}. Schematic for the irradiation of a transistor is shown in Fig. 1b, and resultant changes in threshold voltage is shown in Fig. 1c. ToF-SIMS indicates that He^+-induced trapped charge is introduced because of preferential oxygen vacancy generation.

Experiments were also conducted to induce novel properties in 2D transitional metal dichalcogenides (TMD). Focused ion beam induced etching was utilized as a top-down method to create TMD nanoribbons with < 10 nm resolution[2]. The nanoribbons demonstrated width-dependent transport properties as well an anisotropic Raman response (Fig. 1d). A focused He^+ beam was also used to induce defects within single layer and multilayer WSe_2[3,4], which results in tunable transport properties. Pseudo-metallic behavior was induced by irradiating the materials with a dose of ~$1x10^{16}$ He^+/cm^2 to introduce percolating defect states (Fig. 1e), and subsequent temperature-dependent transport measurements suggest a nearest neighbor hopping mechanism is operative. The metallic transport properties were utilized to direct-write resistor-loaded inverters and edge contacted transistors in single flake of material. These studies demonstrate the capabilities of focused beams as rapid prototyping instruments.

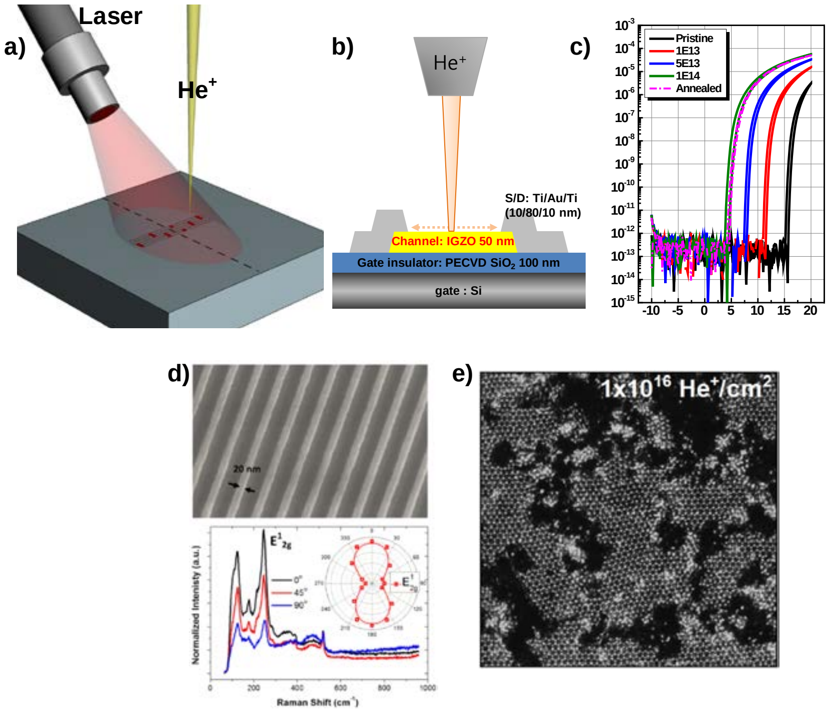

Figure 1. a) Schematic of focused laser and focused He^+ beam setup used for nanoprocessing techniques. b) Schematic of IGZO thin film transistor (TFT) in which the channel was irradiated with a focused He^+ beam. c) Transfer curves for IGZO TFTs which were exposed with varying doses of He^+. d) WSe_2 nanoribbon created by focused beam induced etching with a XeF_2 reactive gas. Raman anisotropy was demonstrated, where θ is the angle between the nanoribbon axis and the polarized excitation laser. e) Scanning transmission electron microscopy (STEM) image of single layer WSe_2 which was irradiated with He^+ to induced percolating defect networks.

References

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