Using FIB-SEM as a Platform for the Positioning and Correlated Characterization of III-V Nanowires

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The focused ion beam - scanning electron microscope (FIB-SEM) instrument is a well-established and versatile tool for the fabrication, modification and characterization of a variety of samples, all in a single instrument [1]. This makes the instrument a powerful and flexible platform for experimental work at micro- to nanoscale. To demonstrate this flexibility, we present its role at several stages in the fabrication and correlated characterization of III-V semiconductor nanowires, complex nanostructures and a promising material system for future optoelectronic devices (e.g. solar cells, LEDs, etc.) [2].

We demonstrate how the FIB-SEM has the power and flexibility to enable position-controlled nanowire growth via direct patterning of the growth substrate. A range of patterning conditions have been applied to the same sample by FIB-milling arrays of holes in a 40 nm thick SiO_x thin film on Si(111) substrate using varying milling parameters. Self-catalyzed GaAsSb nanowires are then grown with molecular beam epitaxy [3]. After nanowire growth, SEM imaging demonstrates that high yields of vertical uniform nanowires have been achieved (Figure 1). Using computer vision on the SEM images, statistics on metrics such as nanowire yield, catalyst diameter and deviation from the intended position can be determined and are shown to be controlled by FIB patterning parameters [4].

To go beyond nanostructuring and morphology-based analysis, more extensive structure-property studies can be performed on positioned nanowires directly in the FIB-SEM. General-use FIB-SEM chambers are reasonably spacious, operate at relatively soft vacuum levels and commonly feature a range of in-chamber tools (microprobes, lift-out needles, gas injection needles, etc.). These tools provide significant sample manipulation capabilities and can potentially be further modified with the ion beam and deposition gases [5]. For the present nanowire example, in-chamber microprobes allow for two-point *I-V* measurements on individual as-grown nanowires [6] as shown in Figure 2(a,b). Recombination losses can be studied with electron beam induced current (EBIC) measurements using the electron beam, and simple mechanical testing can be done using microprobes or lift-out needles [7].

FIB-SEM system functionality can be further extended to control parameters such as temperature by taking advantage of commercially available MEMS chips, mounted to a simple stage adapter and connected to an electrical feedthrough (Figure 2(c)). These miniaturized "lab benches" offer added functionality and could also be tailored to suit specific experiments by FIB milling and deposition. Finally, the in-chamber tools and deposition capabilities make FIB-SEM well suited to identify, isolate and transfer individual specific nanowires to various specimen supports (such as MEMS chips) for further correlated characterization (e.g. transmission electron microscopy).

The range of complementary techniques and approaches available in a single instrument demonstrates the potential of modern FIB-SEM instruments as an all-round toolbox for developing, manipulating and understanding complex nanostructures, such as III-V nanowires, for device applications [8].

References:
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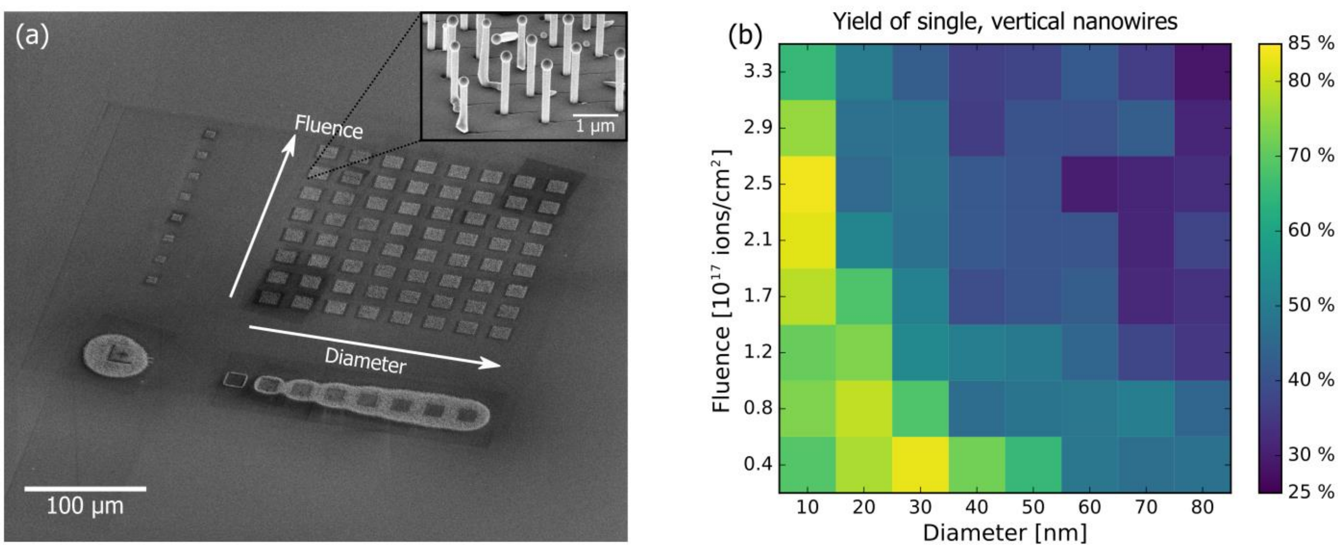

Figure 1. (a) Nanowire arrays defined by FIB patterning. Inset: details of a nanowire array. (b) Yield of single vertical nanowires as function of milling fluence and pattern hole diameter for each array in (a).

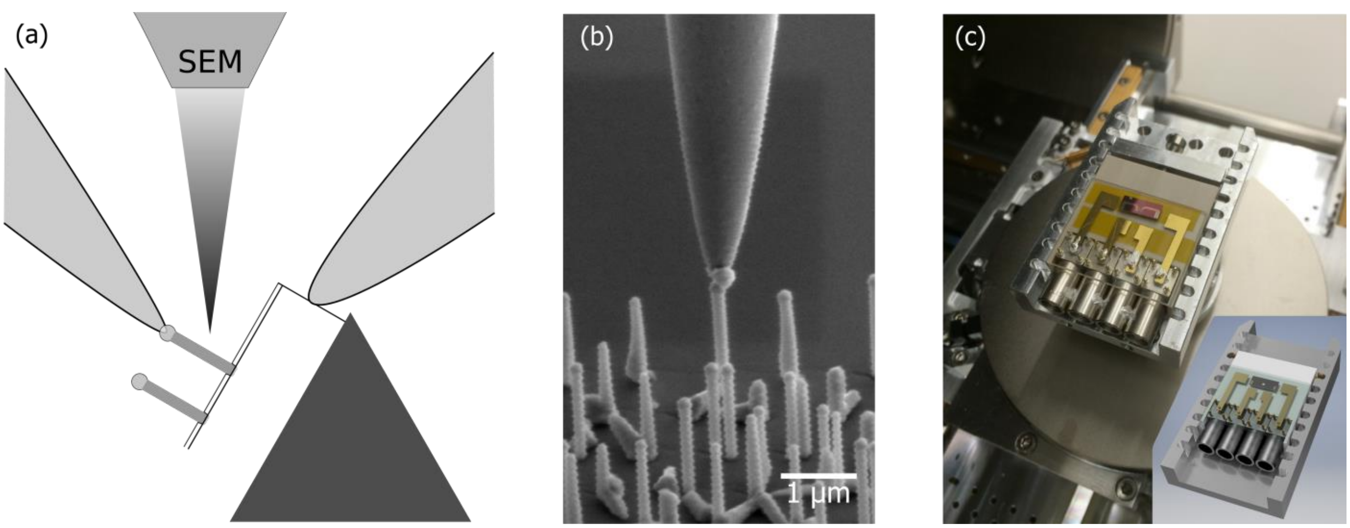

Figure 2. (a) Schematic for two-point probing of single nanowires on substrate. (b) *I-V* probing of an as-grown nanowire. (c) Prototype of generic MEMS chip stage adapter. Inset: 3D design model.