Local, direct-write, damage-free thinning of Germanium nanowires

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Nanowires from silicon or germanium represent unique material systems for exploring phenomena at the nanoscale. Commonly, a process called vapor-liquid-solid (VLS) growth in conjunction with gases like silane (for silicon nanowires) or germane (for germanium nanowires) is employed to fabricate the crystalline nanowires. Additionally, in most cases a catalyst species (e.g. gold) is required to trigger the nanowire growth. Depending on the VLS process parameters the shape, length and thickness of the resulting nanowires can be controlled to some extent. [1]
Doping of nanowires allows fabricating p-n junctions enabling transistors. The morphology of the channel size influences the electrical properties. Chemically synthesized nanowires can be used as nanoelectronic devices such as nanowire transistors, sensors and photovoltaic cells [2].
The possibility of custom-tailoring the diameter of nanowires would open new possibilities for improving the nanowire transistor performance (e.g. by reaching the ballistic limit) or influencing the properties of nanowire photovoltaic devices.
However, reducing the diameter of nanowires in a controlled way after the growth is an unresolved challenge. Conventional methods such as focused ion beam (FIB) processing cannot be employed due to the inevitable ion implantation and amorphization that would alter the electrical properties of a nanowire dramatically.
As a way to overcome this problem a technique called focused-electron-beam-induced etching (FEBIE) is suggested. In contrast to FIB processing this method does not exhibit alien element implantation and retains crystallinity. However, developing an efficient, reliable, non-spontaneous and reproducible FEBIE process (which always requires an etchant) is difficult. For silicon and germanium such a FEBIE process based on molecular chlorine in a conventional scanning electron microscope (SEM) has been developed recently [3]. In contrast to established etchants like xenon difluoride the chlorine-based approach does not exhibit spontaneous etching at all, which would be a show-stopper for this particular application of nanowire thinning.
We show that thinning of nanowires using the suggested FEBIE process based on chlorine can be successfully performed in a highly controllable manner. The principle of the FEBIE process allows for continuous visual verification of the current nanowire diameter at any time during the thinning process. Due to the absence of spontaneous etching the FEBIE process can be stopped by simply blanking the electron beam, immediately halting the localized chemical reaction that mediates the thinning. Depending on the employed electron beam parameters thinning to any desired diameter can be performed within minutes.
The final thinned germanium nanowires have been extensively investigated. Besides topography and SEM imaging, their electrical properties were analyzed. Electrical characterization of thinned nanowires was performed by electrical measurements such as 2-terminal and 4-terminal measurement either in-situ or outside of the SEM chamber.

References

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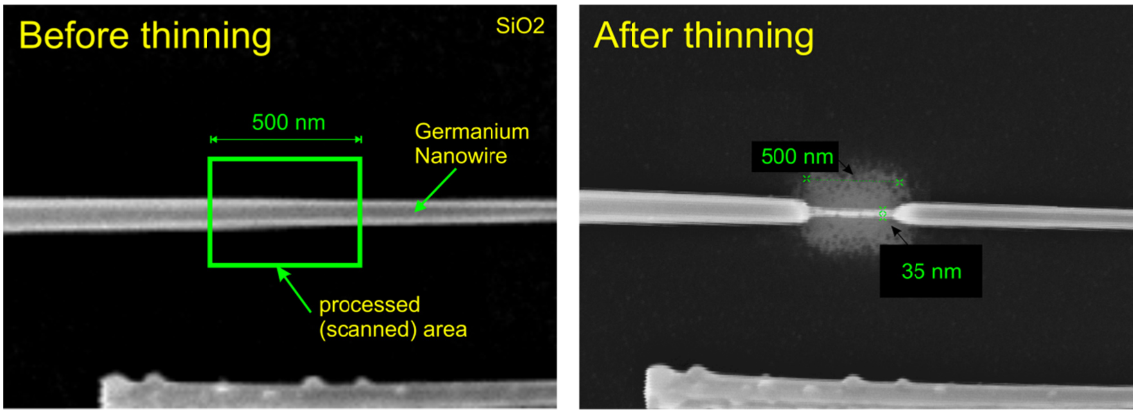

Fig. 1: Proof of concept: SEM images of a germanium nanowire before thinning (left) and after thinning (right). Chlorine-based FEBIE has been carried out for 5 minutes within the area illustrated by the rectangle. After thinning (right) the nanowire's diameter within the processed region could be reduced by about 80%.

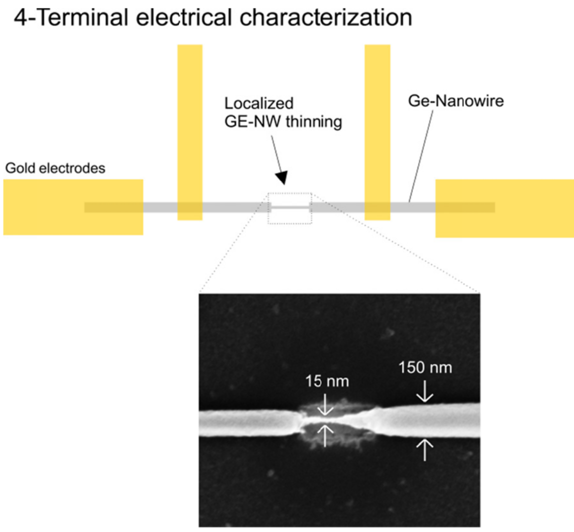

Fig. 2: Measurement setup for the electrical characterisation of a germanium nanowire. By FEBIE the diameter could be reduced to only ~15nm. Electrical measurements can be performed before, during and after the thinning procedure.