EXPERIMENTAL STUDY ON THE RAYLEIGH INSTABILITY OF GOLD NANOWIRES

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Research on the physical and chemical properties of metallic nanowires has attracted increasing interest due to potential applications of such wires in many future nanodevices [1]. In particular, a reliable thermal stability of nanowires is necessary for their implementation as either building blocks or interconnects in nanoscale devices. Models predicted that due to the high surface-to-volume ratio, nanowires become unstable particularly at elevated temperatures when the mobility of atoms by diffusion is higher [2]. Recently, it has been demonstrated experimentally that Cu nanowires with diameter 30-50 nm fragment due to the Rayleigh instability when exposed to temperatures as low as 400 ^{o}C [3]. Further, it is expected that even thinner nanowires exhibit instabilities already at room temperature [4, 5]. Similarly, large low-frequency resistance fluctuations of metallic nanowires were reported recently that occur above a certain temperature due to morphological instabilities [6]. All these findings raise concern under which conditions metal nanowires can be used as interconnects. In addition, thermal annealing is often used to improve desired physical properties of nanowires [7]. Therefore, a sound knowledge of thermal stability is thus necessary, not only for the industrial implementation where higher temperatures are required for both production and performance, but also for an optimized production of defect-free nanowires by thermal annealing.

In this work, we have systematically investigated the instability of Au nanowires annealed isothermally at different temperatures. We show that the wires driven by Rayleigh instability undergo various configurational changes and finally break up into a chain of spheres at temperatures well below the bulk melting point (Figure 1). We observed how the final morphology is influenced by the three parameters: wire diameter, temperature, and annealing time. Both the average diameter of the nanospheres formed after decay and the spacing between adjacent spheres are larger than that predicted by linear stability analysis for materials with isotropic surface energy, indicating a stabilization effect due to surface energy anisotropy.

In addition, a reliable control over this instability process can provide an effective, powerful, and economical technique for producing self-assembled nanosphere chains on a relatively large scale by using Au nanowires as starting point. This kind of structures has unique properties for many promising applications such as plasmon waveguides where near-field coupling between surface plasmon-polariton modes of neighboring particles is used to guide light below diffraction limit [8]. The fabrication technique can also be extended to different materials and substrates.

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Figure:

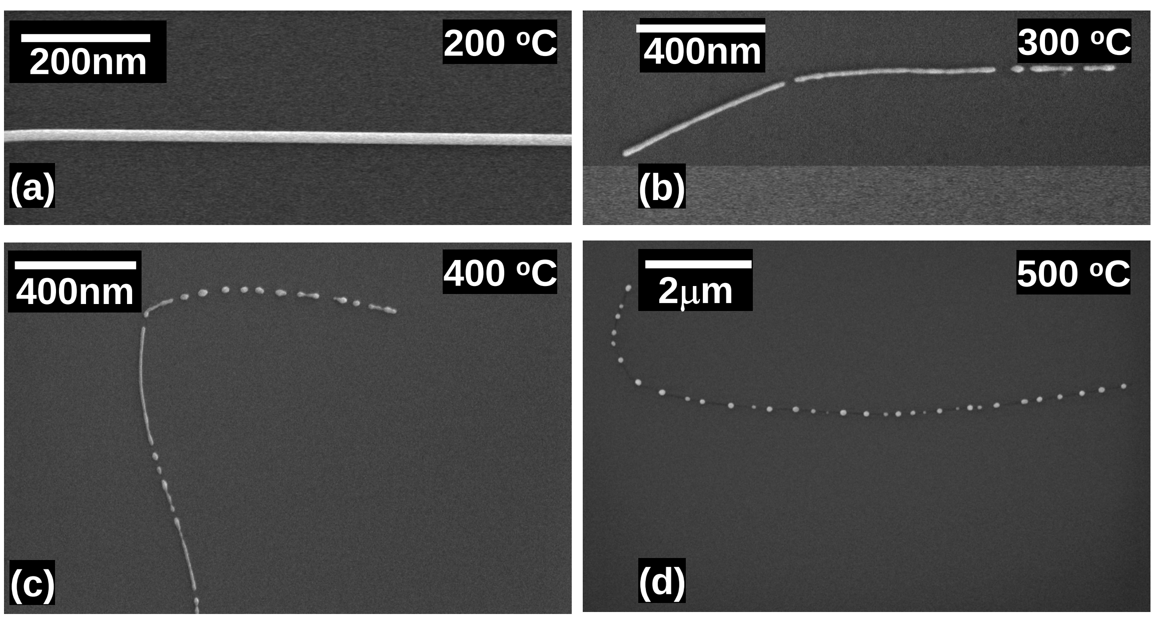

Figure 1. HRSEM images of 25 nm gold wires after annealing at different temperatures. Annealing time was in all cases fixed to 30 min. (a) A Wire preserve its shape after annealing at 200 ^{o}C. (b) At 300 ^{o}C, perturbations are developed resulting in fragmentation (c) At 400 ^{o}C, a wire decay into much shorter section. (d) Finally, at 500 ^{o}C wires transform into chains of nanospheres.