Influence of O contamination and Au cluster properties on the structural features of Si nanowires

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A B S T R A C T
Silicon nanowires (Si NWs) are the emerging nanostructures for future nanodevices. In this work we have prepared them by electron beam evaporation (EBE) through the vapor–liquid–solid (VLS) mechanism. We discuss the growth of epitaxial NWs by EBE and the possibility to control their orientation and length by changing the experimental conditions. Moreover, the effects of the surface contamination and of the Au cluster preparation on the NWs structural properties and density will be discussed. We demonstrate that any O contamination has to be avoided since just a very thin native SiO2 layer stops ad-atom diffusion on the surface and inhibits the NWs growth. Au cluster preparation has a determinant role too: by varying the procedure for their formation, it is possible to change NWs density and length. In particular, we observed that by evaporating Au on the heated substrate, the droplets active to promote NW growth are immediately formed and a faster growth process starts. The growth rate is about a factor of 4 times higher than in the sample where the Au is evaporated at room temperature and the cluster formed after a subsequent thermal annealing. On the contrary, the slower process allows the atom arrangement and ordering in an epitaxial manner, and a precise control of NW orientation can be achieved.

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1. Introduction

The scaling down of the device dimensions will continue for a while but, since we are reaching the physical limits of such an approach, new structures have to be considered for improving device performances. Among these, the researcher community is devoting a large interest on Si nanowires (NWs) as building blocks for future devices, solar cells and bio/chemical sensors [1–3]. NWs can be easily obtained through a self-assembling method, named vapor–liquid–solid (VLS) [4]. Au has been usually chosen as a catalyst, because the Au/Si eutectic point is at a low temperature (363 °C). Si NWs fabrication was accomplished by a variety of techniques such as chemical vapor deposition (CVD), molecular beam epitaxy (MBE) or thermal evaporation [4–6]. Electron beam evaporation (EBE) is still an unexploited technique [7,8], but it has recently demonstrated [9] the possibility to grow Si NWs epitaxially to the substrate with the control of the growth mechanisms and orientation under non-UHV conditions.

In this paper the effects of the surface contamination and of the gold cluster preparation on the NWs structural properties and density will be discussed.

2. Experimental details

The evaporation system is a modified Varian physical vapor deposition chamber. Its base pressure is about 1–2×10−8 mbar. High purity Au pellets and Si ingots are stored in different water-cooled crucibles inside the chamber and they can be subsequently used as sources. They are evaporated using an electron beam with a maximum power of 3 kW. The deposition flux and fluence are monitored in situ by a quartz microbalance. Under these conditions the substrate is eventually heated through Joule effect.

(111)-oriented Si pieces are used as substrates. Selective HF etching (5% diluted in de-ionized water for 5 min) is initially performed to remove the native SiO2 layers. Then, samples are located in the vacuum chamber. After that a 2 nm-thick Au layer is evaporated maintaining the sample at room temperature (RT). A continuous Au layer is formed and the sample is extracted from the chamber for a subsequent furnace annealing at a temperature of 480 °C for 1 h to induce the formation of Au clusters. A second HF etch is necessary to remove the native SiO2 layer grown between the Au clusters before finally loading the sample again in the vacuum chamber for Si evaporation. We verified by comparing SEM images and measuring the density before and after the etching that this has no effect on the cluster distribution. This sample will be referred to as type A. A specific sample is not etched to investigate the role of O contamination on NWs growth (type B). Si is then evaporated maintaining the substrate temperature fixed at 480 or 510 °C. The