GROWTH OF Si AND SiGe NANOWHISKERS BY MOLECULAR BEAM EPITAXY; X-RAY SCATTERING AND ELECTRON MICROSCOPY INVESTIGATIONS

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Metal, ceramic and semiconductor nanowhiskers and nanowires are of increasing interest due to their potential applications in nanotechnology devices [1]. Growths of silicon nanowires by chemical vapor deposition, using the vapor-liquid-solid (VLS) mechanism, have been reported by many authors. In the VLS growth mechanism, the nanowire grows from a gold/silicon catalyst droplet located on the top of the wire. The VLS mechanism can be also used in order to grow silicon nanowires by molecular beam epitaxy as reported recently by Schubert et al [2]. However, a very limited number of papers describe the growth of SiGe nanowires or nanowhiskers [3].

In our contribution we will show how to grow silicon and silicon/germanium nanowhiskers by molecular beam epitaxy on silicon (111) and discuss structural properties of our nanowhiskers as determined by X-ray scattering and electron microscopy observations. X-ray scattering experiments have been performed at the ESRF on ID01, BM02 and BM32 beamlines.

The growth procedure of silicon nanowhiskers by molecular beam epitaxy is relatively simple. After silicon oxide thermal desorption and growth of a silicon buffer layer, 50 nm thick, a thin gold film is deposited on reconstructed 7x7 silicon surface at room temperature. In order to cover the surface of silicon by gold droplets, a thermal treatment of the gold film is performed at 500°C. The size and the density of droplets depend on the thickness of the gold film and on the temperature and time of thermal treatment. After droplets formation silicon surface is exposed to a silicon flux. This induces the growth of nanowhiskers. In figure 1(a) we show a scanning electron microscopy (SEM) image of silicon nanowhiskers grown by the described above procedure. The mean diameter at the basis of whiskers is about 100nm and their length can reach 1 micron. The growth of whiskers results from the difference of the silicon growth rate under the gold droplet and between droplets. Each whisker is surrounded by a deep inclusion (see figure 1 (a)) which may correspond to the mass transport from the silicon surface to the top of the whisker where is located the silicon reach gold droplet.

Silicon whiskers have a very complex structure. From the SEM image shown in figure 1 (b), one can deduce that the walls of whiskers are not flat but built by two families of facets [4]. The presence of these two families of facets was also confirmed by grazing incidence x-ray scattering (GISAX) measurements. In figure 2 we show GISAX observations made in the <-1-1 2> direction. The same image was observed be rotating the sample by 60°. This indicates the hexagonal shape of our nanowhiskers. In figure 3 (a) and 3 (b) we show transmission electron microscopy (TEM) image of the silicon whisker with few germanium layers. In order to grow germanium layers silicon deposition has been interrupted and the sample was exposed to a germanium flux.

From the TEM image shown in figure 3 (a) and in figure 3 (b) we determined the growth rate difference between the area around the whiskers and inside the whiskers. The silicon growth rate inside the whiskers is 5.5 times faster than the growth rate of the bulk silicon. However this growth rate difference may depend on the shape, diameter of nanowhiskers and on the growth conditions (i.e. growth temperature and/or silicon flux). The thickness of the germanium layers between the whiskers (see figure 3 (b)) is about 3 monolayers which indicates that in this area germanium layers are composed of almost pure germanium. Inside the whiskers, the thickness of germanium layers is much higher thus indicating a very high intermixing of germanium with silicon. We can propose the following mechanism inducing this silicon germanium intermixing. During germanium deposition silicon is “provided” by the gold droplet. Inside the whisker, below the droplet, does not grow a pure germanium but silicon germanium alloy. This will be discussed in our contribution on the basis of our results from anomalous x-ray diffraction performed at the Ge and Au absorption edges. Germanium/ silicon lattice parameter distribution inside the nanowhiskers, composition of the germanium/ silicon layers inside the whiskers, composition inside the droplets and gold diffusion into silicon and germanium will be also discussed.

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References:

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Figures:

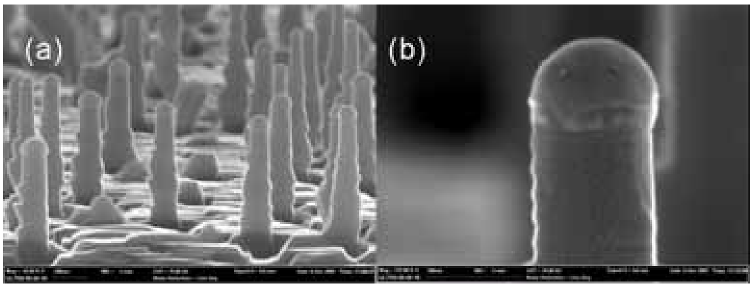

Figure 1: SEM images of (a) an assembly of silicon nanowhiskers and (b) the top of a silicon nanowhisker with a periodic faceting.

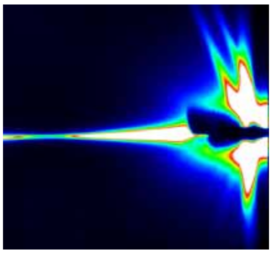

Figure 2: GISAXS pattern in the <-1-1 2> direction showing two facets at 11.2° and 23.5° from the <111> direction

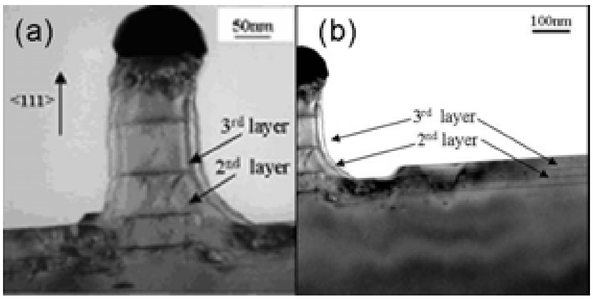

Figure 3: TEM observations of (a) the Ge layers into a silicon nanowhisker and (b) the Ge layers between nanowhiskers