Silicon Nanowhiskers Grown on <111> Si Substrates by Molecular Beam Epitaxy

P. Werner, L. Schubert, N. D. Zakharov, G. Gerth, F. M. Kolb, and U. Gösele
MPI für Mikrostrukturphysik, Weinberg 2, D-06120 Halle (Saale), Germany

Silicon nanowhiskers are of increasing interest due to their physical properties as well as their potential for new nanodevices (1, 2). They are normally grown by chemical vapor deposition (CVD) (3) and gas-source molecular beam epitaxy (GS-MBE) (4,5). In the case of the CVD method small droplets of metals, such as gold, are forming low-temperature eutectic liquids with silicon acting as a seed for the whisker growth. The silicon is preferentially incorporated via the liquid silicon-metal droplet. This technique is referred to as the vapor-liquid-solid mechanism (VLS-mechanism) (6,7). It is characterized by a growth process at the whisker/droplet interface by incorporation of Si atoms coming from the liquid droplet. However, this growth process is still under discussion and might strongly depend on the specific techniques applied.

We investigate the growth of Si and SiGe nanowhiskers by molecular beam epitaxy (MBE) by using small metal clusters at the silicon interface as seeds. The in-situ generation of the metal clusters as well as the growth parameters of the whiskers are discussed. The whiskers have a diameter in the range of 50 to 200 nm. Fig.1 presents an example of whiskers grown on a <111> substrate. In this particular case the whiskers have an average length of about 400 nm. The gold droplets (dark) are visible at their top.

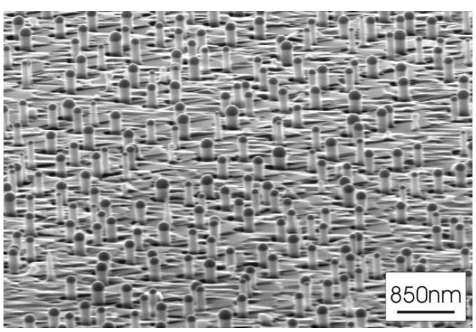

Fig.1 Scanning electron microscopy image of Si-whiskers grown on a <111> Si substrate at a Si growth rate of 0.5 Å/s for 60minutes.

A scheme of the growth structure is given in Fig.2. The size l denotes the length from the base to the top of the whisker, l_S the thickness of the grown Si layer and $l_{tot} = l + l_S$ the total length of the whiskers including the base layer, respectively. The observed growth is nearly linear in time. However, the experimentally observed radius dependence of the growth velocity of the nanowhiskers is opposite to what is known for VLS growth based on chemical vapor deposition. Fig.3 presents a typical example: for a given growth time, the length l of the whiskers is systematically longer for whiskers with smaller diameters d. The data fit correlates to the relation:

$l = Cd^m$ with m ≈ -1. C denotes a constant. In the presented growth model we explain this behavior by a Si ad-atom diffusion on the surface of the whiskers. This diffusion related component leads, for the case of MBE growth, to a larger growth rate for nanowhiskers with smaller radius.

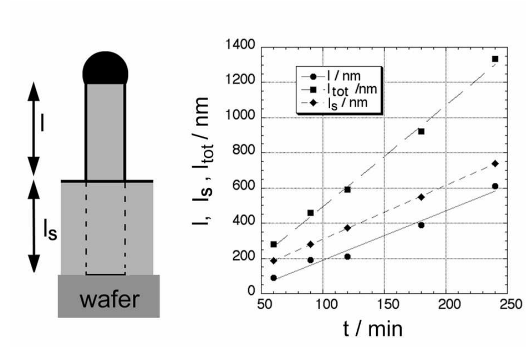

Fig.2 Correlation between the length l and diameter d of Si whiskers. The experiments were performed at 525°C

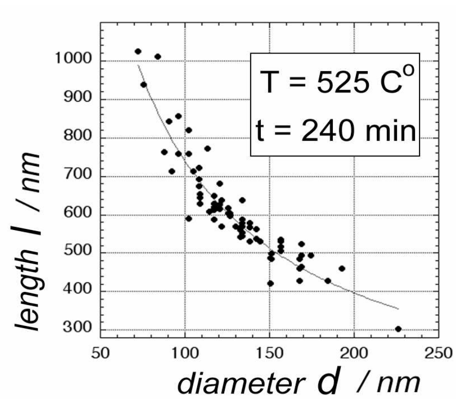

Fig.3 Correlation between the length l and diameter d of Si whiskers. In this specific case the growth experiments were performed at 525°C for 240 min.

Additionally thin Ge layers in the nm-range can be incorporated into the Si whisker. Structural phenomena of such Si-Ge nanoheterostructures are discussed including doping phenomena.

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