Heteroepitaxial Growth of Nanopillars on Si

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There is widespread interest in developing methods to form arrays of 3-dimensional nanostructures on semiconductors for electronic, optoelectronic, and electrochemical applications (e.g., detectors, photonic lattices, single molecule sensors). The direct growth of heteroepitaxial nanostructures is of particular interest for several reasons: large lattice mismatches can be rapidly accommodated in pillar growth, nanoscale structures tend to exclude defects to the lower energy surface region, and novel quantum structures can be devised on a Si platform. We are exploring a variety of selective growth techniques to form such heteroepitaxial nanostructures on Si. One recent area being widely pursued is the formation of Si and Ge nanowires by VLS (vapor-liquid-solid) growth. However to date most of this work has involved random growth from colloidal Au nanoparticles followed by manipulation of the wires and subsequent studies of their electronic, photonic, and chemical sensing properties.

In this highlight we focus on the materials science of selective Ge CVD growth on Si by the VLS method using 5 to 30 nm Au dots to seed the growth. Growth is carried out in a UHV cold wall system using digermane at 400 to 600C on Si (100) and (111) at gas phase MBE pressures from 10^{-6} to 10^{-4} Torr; Au dots are formed by deposition at elevated temperatures in a separate UHV system on a H terminated Si surface. Fig. 1 shows an example of the Ge nanopillars grown just above the AuGe eutectic temperature. The Ge grows selectively on the Au regions but includes lateral growth leading to coalescence of pillars. RBS demonstrates that the Au liquid eutectic rides on top on the Ge during growth and determines the growth rates. The Au mediated growth is quite distinct from gas and solid phase growth of group IV epitaxy, with slower kinetics and an opposite orientation dependence of the fast growth direction observed. The growth on (111) surfaces is a more well-defined layered growth than for the (100) with faster lateral and overall growth rates at the higher temperatures.

At the lower temperatures and higher pressures for the (111) orientation we see a dramatic transition from a layer-like nanopillar growth to the onset of an extremely rapid axial nanowire growth as shown in Fig. 2. This transition to nanowire growth is consistent with previous studies that have been carried out at higher pressures (typically 10^{-2} T to atmospheric pressure) and show a nanowire growth morphology that strongly favors the <111> growth direction. Results suggest this transition from layer-like nanopillar growth (not previously described) to the commonly discussed nanowire growth is a nucleation limited process. By manipulating the growth parameters we anticipate being able to control the growth between these two regimes to form a variety of 3D structures on lithographically patterned substrates.

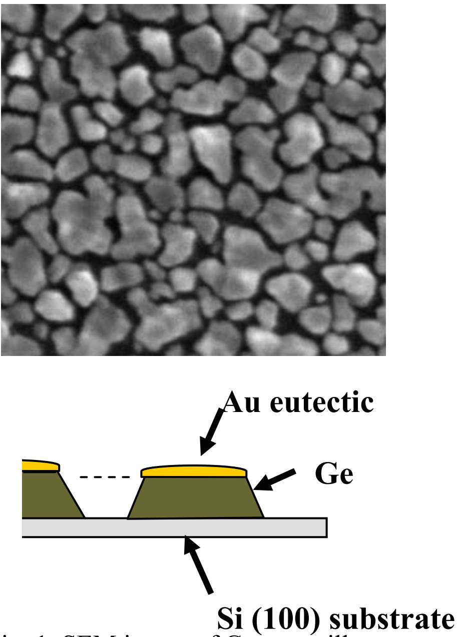

Fig. 1 SEM image of Ge nanopillars grown on Si (100) at 400C, 10^{-4} T after coalescence; a schematic of the nanopillars.

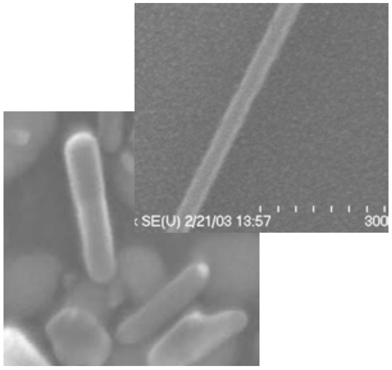

Fig. 2 SEM of transition region showing 30 Nm Ge nanowires on Si (111) at 400C, 10^{-4} T.