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Heterogenous nucleation of catalyst-free InAs nanowires on Silicon

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Semiconductor nanowires (NWs) offer exciting opportunities for both fundamental studies and technological applications [1]. In particular, monolithic integration of III-V nanowires on silicon substrates has gained considerable research interest because of its significant potential for the realization of electronic and opto-electronic devices. One of the most effective ways to fabricate III-V nanowires is the vapor-liquid-solid (VLS) technique using foreign metal catalysts, such as gold [2]. However, the use of Au introduces the possibility of unintentional incorporation of impurities degrading electronic and optical properties of the grown semiconductors [3]. Triggered by the need to avoid metal contamination in the NWs and favour the full compatibility with the present silicon technology, in the last years catalyst-free growth techniques have been intensely explored [4,5]. Direct growth of III-V NWs, in particular InAs on silicon, has critical issues. InAs NW growth is usually accompanied by unwanted parasitic island formation and both continue to nucleate even after long growth times, causing neighboring nanocrystals to coalesce. Not only does coalescence reduce the density of freestanding NWs, it also results in the deterioration of the NW morphological, structural, and optical properties. For most practical purposes, it is desirable to suppress the coalescence process by reducing the initial nucleation density as well as inhibiting new nucleation. However, there are very few reports on density-control methodologies for InAs NWs on silicon [6,7]. Therefore, there is an urgent need for understanding the nucleation mechanisms of NWs and islands on silicon substrate to achieve control on their density. We present a new approach to prepare Si (111) surfaces for the controlled growth of InAs NWs by chemical beam epitaxy (CBE). We show that sputtering of the surface of Si (111) surface enhances the nucleation of InAs crystals (NWs and islands) while no nucleation occurs on non-sputtered Si (111) surfaces under identical growth conditions. The substrate preparation protocol is described as follows: commercially available Si(111) substrates covered with a native of 20 nm thick thermal-oxide layer were used; the oxide was completely removed by a 2 min buffered oxide etch (BOE) with an etch rate of about 90 nm min^{-1}. No NW growth occurred on non-sputtered silicon substrates. Subsequent surface treatment involved sputtering the silicon surface with controlled argon or SiO_2 energetic particles. Energetic argon particles were obtained by an inductively coupled plasma (ICP) sputtering system, while SiO_2 particles are obtained by a radio-frequency (RF) magnetron sputtering system. After sputtering and prior to NW growth, the sputtered substrates were again etched for 2 min in BOE to remove residuals and deposited oxide. Figure 1 shows plan-view SEM micrographs of InAs NWs grown on non-sputtered Si(111) (Fig. 1a) and on sputtered Si(111) substrates (Fig. 1b). SEM micrographs in figures 1a and b show that InAs crystals nucleate only on the sputtered Si(111) surfaces. The InAs crystals shown in figures 1b consist of NWs and islands.

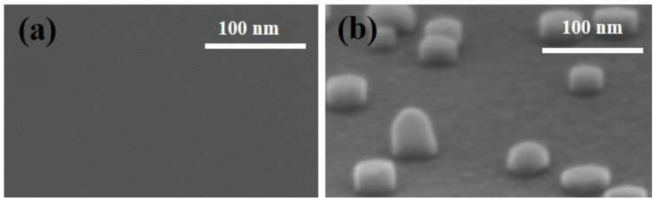

Fig. 1. Plan-view SEM micrographs of InAs crystals grown under identical conditions on (a) non-sputtered and (b) sputtered silicon substrates.

We argue that the enhancement of nucleation on sputtered samples stems from the formation of surface defects associated to the sputtering process that serve as preferential physical nucleation sites [8]. Although the nucleation of parasitic islands cannot be completely inhibited, we show that the yield of NWs with respect to islands can be maximized by proper choice of in situ growth and ex situ sputtering parameters obtaining InAs NW densities in the range of 1-30 NWs/μm^2 with a yield of 50%.

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