Spontaneous growth of uniformly distributed In nanodots and InI_3 nanowires on InP induced by a focused ion beam

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Focused ion beam (FIB) milling can be used both as a top-down (patterning) as well as a bottom-up structuring tool. Bottom-up applications include self-assembly at random or specific locations during or after ion irradiation. Nano-crystallite growth on FIB irradiated areas has been shown for GaAs and InAs[1].

We show spontaneous growth of hemispherical nanodots due to differential sputtering by the 30 keV Ga^+ ions and of wires due to chemical reactions with iodine on the surface of FIB-irradiated areas on a (100)InP substrate.

Hemispherical islands consisting mainly of In grow on InP during sputtering. Diameter and height of a typical island are 42 nm and 7 nm, respectively, determined by scanning electron and atomic force microscopy (Figures 1 and 2). Density of the nanodots was measured to be $2x\ 10^{10}$ cm^{-2}. The size of the nanodots is relatively stable over a wide range of ion fluences ($5x\ 10^{12}$ $-1x\ 10^{15}$ cm^{-2}). Size can be increased by heating the substrate above 156°C, the melting point of pure In. Ga content even reduces the melting point. The differential sputtering rate, due to differences in the surface binding energies of binary semiconductor materials was identified as the main cause for the growth of the nanodots. The surface is depleted from the light element and the heavier element coalesces to form dots. Formation of dots is thought to be enhanced by ion-enhanced surface diffusion, considering a temperature-dependent diffusion coefficient. As a comparison, it has been reported that the minimum Ga droplet size on GaAs is 120 nm[2]. The minimum size in this case is limited by the low melting point of Ga (29.8°C) and the precipitation of Ga on the surface originating from the Ga^+ ion beam. Similar growth is expected for all materials with a significant differential sputtering rate (e.g. GaX, InX, where X=P, As, N, Sb).

Reactive gases can be inserted into the FIB-chamber to enhance sputtering rate (focused ion beam gas enhanced etching, FIB-GAE) or to deposit metals, insulators or carbon (focused ion beam chemical vapor deposition, FIB-CVD). These gases may form involatile reaction products on areas previously irradiated by the FIB. For InP, iodine was used to enhance the sputtering rate. The reaction between InP and I_2 does not require simultaneous ion irradiation. The main reaction products are GaI_3, PI_3 and InI_3. InI_3 stays on the surface due to its low vapor pressure. By patterning the area along parallel lines with FIB and heating the substrate, InI_3 wires with diameter below 100 nm could be grown. Ion trenching creates sharp V-shaped grooves at the bottom of which wire growth is confined to 2 dimensions. Surface rippling with controllable wavelength under ion bombardment has been reported for different materials[3] and could be also be used as a template for nanowire fabrication.

Localization and density of the islands and wires can be controlled with beam current, scanning strategy, irradiation time and substrate temperature.

References:

[1] A. Lugstein et. al, Journal of vacuum science and technology B, **22(6)** (2004) 2995.
[2] A. Lugstein et. al, Journal of vacuum science and technology B, **22(3)** (2004) 888.
[3] L. Jie et. al, Applied physics letters, **88** (2006) 093112.

Figures:

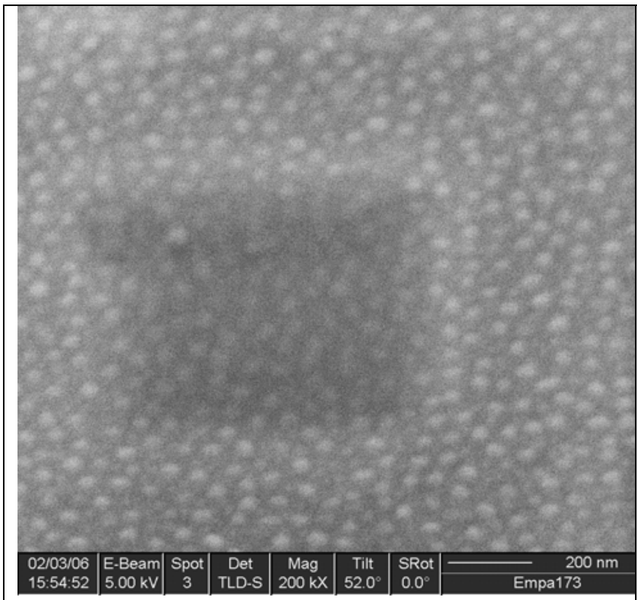

Figure 1: Indium-Gallium quantum dots grown under ion beam irradiation

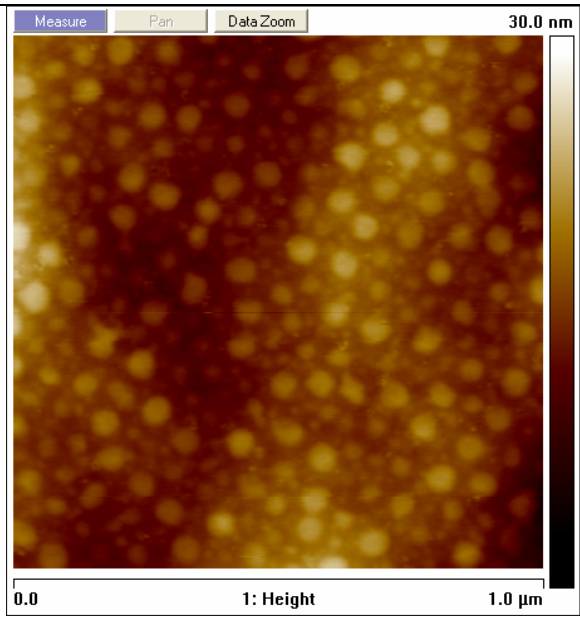

Figure 2: AFM image of the as-sputtered InP surface

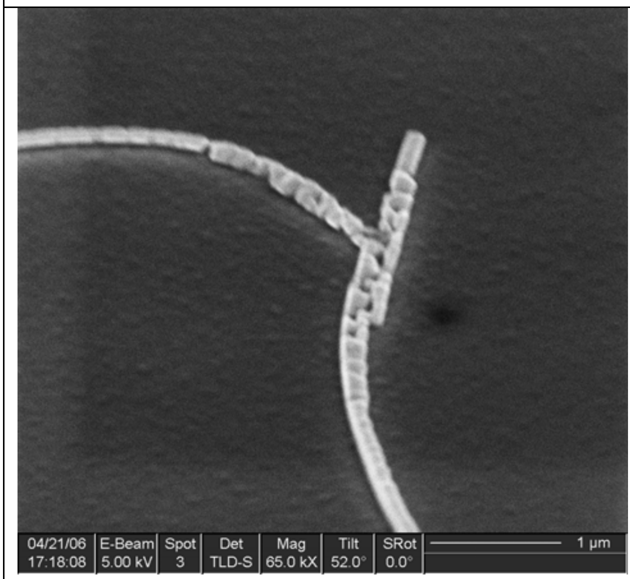

Figure 3: InI_3 nanowire which grows spontaneously under FIB-GAE of InP with I_2.

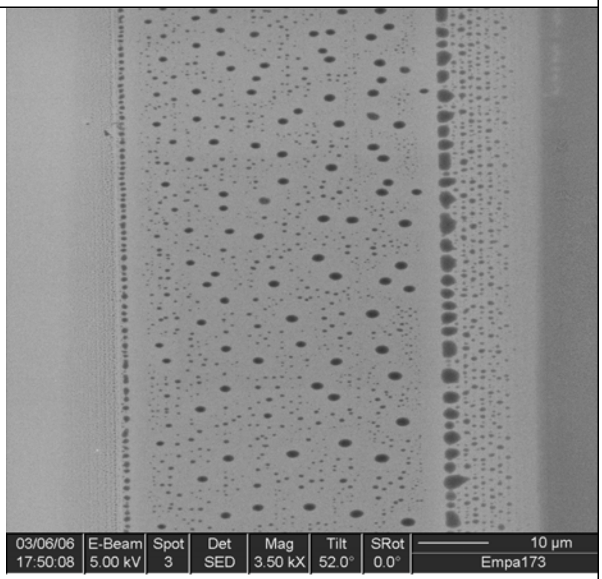

Figure 4: InI_3 rearranges along previously milled lines after heating 10 minutes at 160°C on air.