Template assisted selective epitaxy of InP via MOVPE towards horizontal heterojunctions for tunnel field effect transistors

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A unique confined lateral selective epitaxial growth (CLSEG) [1] technique for next generation semiconductor devices was demonstrated in [2, 3] and termed template assisted selective epitaxy (TASE). This technique is based on the formation of hollow confined structures designed in such a way that subsequent epitaxial growth initiates from a small area of the substrate exposed to the growth environment, dubbed a seed, and continued growth is forced within the template. The benefit of this is the ability to arbitrarily determine the shape and orientation of the grown material to form novel nano-electronic device structures.

Here, results are reported on the fabrication of channel-like nanometer sized horizontal structures, and, the subsequent homoepitaxy of indium phosphide (InP) to demonstrate the potential for TASE to create sharp horizontal heterojunctions that could enable next generation of tunnel field-effect transistors (TFETs) [4].

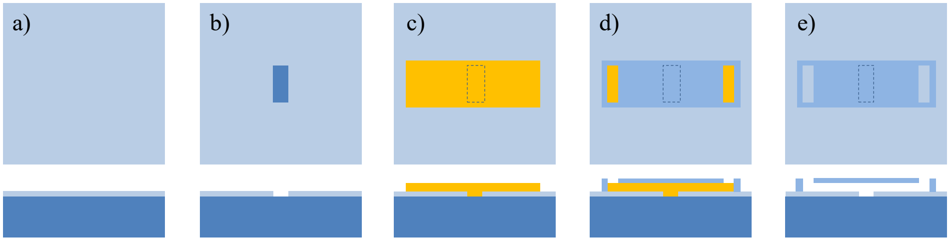

Figure 1. Schematic illustration of process flow. a) blanket PECVD SiO_2 deposition, b) EBL-based formation of seed holes in SiO_2, c) patterning of sacrificial layer, d) patterning of HSQ-based top oxide, e) removal of sacrificial layer. Omitted: the alumina etch stop layer.

Templates were fabricated on (100) n-type InP wafers. First an atomic layer deposition (ALD) Al_2O_3 etch stop layer (omitted in Fig.1) was deposited followed by a plasma enhanced chemical vapor deposition (PECVD) SiO_2 bottom oxide layer. Seed holes were patterned by electron beam lithography (EBL) and etched with inductively coupled plasma etching based on $CHF_3/CF_4/O_2$. The sacrificial layer that defines the cavity was formed by exposing the cavity outline with positive electron beam resist and the top oxide was formed by EBL of hydrogen-silsesquioxane (HSQ). Wafers were then flood exposed with a deep-UV lamp and developed in amylacetate to remove the resist. Finally, the Al_2O_3 etch stop was removed with wet etching. Each die consists of a parametric array of structures of varying characteristic sizes. Along with growth interrupts, this allows for the analysis of the confined growth behavior.

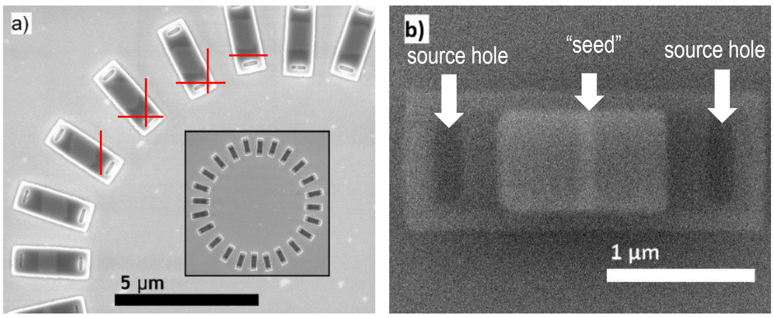

Figure 2. Top view SEM images showing a) an array of rotated templates (the red overlayed lines are meant to guide the eye and show faceting of growth front), b) typical result of a filled template in back scatter mode showing lighter contrast at the seed.

As-processed wafers were diced and loaded into a metalorganic vapor phase epitaxy (MOVPE) system for subsequent growth experiments. Trimethylindium (TMIn) and tertiarybutylphosphine (TBP) precursors were used. Effective growth selectivity was obtained with a growth temperature of 640°C, a group III precursor molar rate of 4×10^{-6} mol/min, and V/III ratio of 400.

Scanning electron microscopy (SEM) characterization of the as-grown samples was employed to determine the success of growth in the template; the top oxide, while present, is thin enough to easily allow electron penetration for good imaging. Images show mostly sharp vertical faceting at the growth front in the [110] directions (Fig. 2(a)) regardless of the overall orientation of the template. The images also suggest growth initiation occurs exclusively at the seed, showing higher local contrast in backscatter mode (Fig. 2(b)), and good selectivity with a lack of dielectric nucleation inside or outside of the template structure.

Transmission electron microscopy (TEM) cross section images from earlier TASE experiments, with SiO_2 based templates but with a slightly different fabrication process flow, confirms seeded growth, good selectivity, faceting at the growth front, and shows conformal growth along the entirety of the structure (Fig.3).

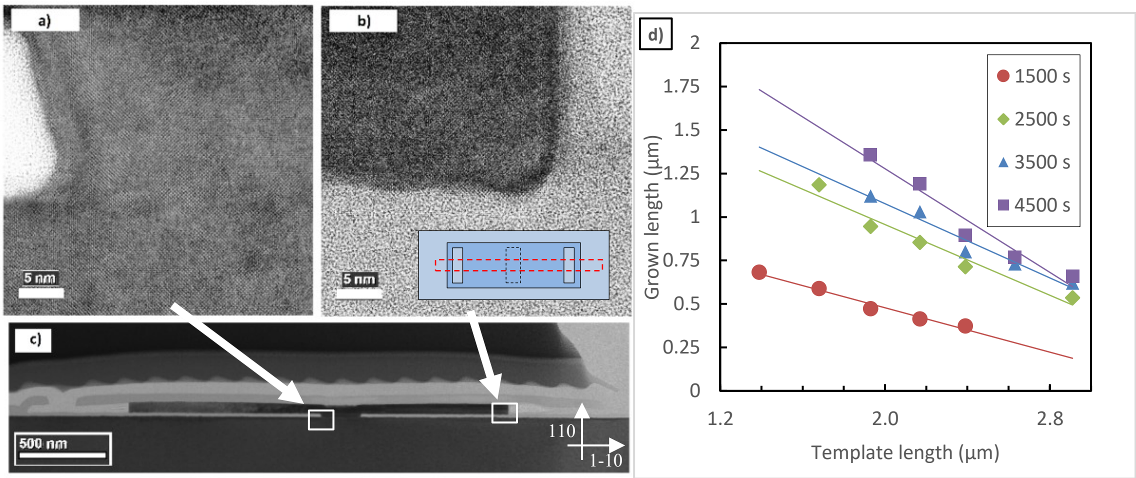

Figure 3. High resolution cross section TEM images of a) the initial growth interface at the seed, b) the final growth front in the template. The inset shows where the lamella used for TEM is taken from (dashed red line). c) Bright field TEM cross section of the entire confined structure. d) summary of four growth runs showing the influence of template length on growth.

Growth interrupt experiments with identical operative parameters were carried out with runs lasting 1500 s, 2500 s, 3500 s, and 4500 s, and utilizing identical samples from the same processing batch. The length of the grown material was measured from the geometrical center of the structure and results were compared for structures of varying length with all other sizes fixed (Fig.4(d)). Initial trials suggest growth rate suppression with increased template length (the distance between source holes). Under the present growth conditions, MOVPE is understood to be mass transport limited [5], so the growth rate reduction could be intuitively explained by the need for precursor material, whose transport is diffusion driven, to cover longer distances.

Future endeavors will build on the sharp faceting to develop heterojunction-based devices while simultaneously exploiting the flexibility and short learning cycle of this approach to collect data on the behavior of MOVPE in confined structures.

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