## Study of InP surfaces after wet chemical treatments

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Today all transistors in integrated circuits are fabricated on Si substrates, in some cases alloyed with limited amounts of Ge. In order to meet the future requirements imposed by the scaling roadmap, the next generation of transistors will be based on III-V compound semiconductors, integrated on a Si substrate [1]. The potential high bulk carrier mobility of these materials can result in improved transistor performance [2,3]. In general, III-V materials are poorly passivated compared to Si and form complex and chemically inhomogeneous and unstable oxides. An oxide removal step is hereby critical since an interface with high defect density will lead to device deterioration. The use of wet chemical treatments have been proven to be effective and practical for semiconductor surfaces. However, the formation of a stoichiometric III-V surface with minimal oxide is still a challenge [4,5].

In order to obtain an adequate understanding of the remaining surface after wet chemical treatment, a profound study of the III-V surface composition and stoichiometry is required. Due to its high surface sensitivity, Synchrotron Radiation Photoemission Spectroscopy (SR-PES) is the optimal method to investigate III-V surfaces. For this work, SR-PES measurements were carried out at the U49-2 PGM-2 beamline at the Bessy-II synchrotron radiation facility within the Helmholtz-Zentrum Berlin. The surface morphology was studied by scanning tunneling microscopy (STM).

As a reference, the composition of an as received InP surface is shown in Figure 1. The fitting model of the P2p and In3d<sub>5/2</sub> spectrum clearly reveals an extensive amount of surface components. It is therefore comprehensible that this will lead to an inadequate starting surface prior to epitaxial growth of the channel layer. Next, it was observed that immersion in various acidic solutions (HCl, H<sub>2</sub>SO<sub>4</sub>) is more effective towards oxide removal as compared to a moderately alkaline treatment (NH<sub>4</sub>OH). However, the InP surface after HCl (and H<sub>2</sub>SO<sub>4</sub> – not shown) still shows a significant amount of surface components (Fig. 2), with detection of P<sup>0</sup>, P<sup>(2± $\Delta$ )<sup>+</sup></sup> suboxides and In<sup>0</sup>, which may imply a non-ideal starting surface towards the next layer deposition.

Due to the presence of defects (e.g.  $P^0$  and  $P^{(2\pm\Delta)+}$  suboxides) after oxide removal, and the fast re-oxidation of InP surfaces, an additional passivation step should be performed prior to atomic layer deposition of a dielectric layer [6]. In this work, (NH<sub>4</sub>)<sub>2</sub>S solution immersion was

used to passivate the InP surface. Figure 2 shows that a  $(NH_4)_2S$  solution can be used to remove the native oxide of InP surfaces. The P2p spectrum clearly shows less surface components, since  $P^0$  and  $P^{(2\pm\Delta)+}$  suboxides are below detection limit. It can also be observed that no  $P_xS_y$  bonds are retrieved in this spectrum since they should be located in the binding energy range of 130 to 132eV. The presence of In-S in the In3d<sub>5/2</sub> spectrum is located at the same binding energy as In<sup>3+</sup>, which makes the distinction and therefore quantification of both components complicated. Although  $(NH_4)_2S$  solution improves the surface stoichiometry, TXRF reveals metal contamination after immersion in the solution, which may be detrimental for device performance.

Recently, we proposed a two-step etching mechanism for InP, which allows for controlled nanoscale etching of the surface [4] and effective oxide removal [5]. It will be shown that this will result in an atomically smooth InP surface with minimal oxide present.

## References

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Figure 2: P2p and  $In3d_{5/2}$  spectra of an InP surface after HCl treatment (top) and the same spectra after  $(NH_4)_2S$  solution immersion (bottom).