

Nanoscale Etching of III-V Semiconductors in Acidic H₂O₂ Solutions

D.H. van Dorp^a, S. Arnauts^a, D. Cuypers^{a,b}, J. Rip^a, F. Holsteyns^a and S. De Gendt^{a,b}

^aIMEC Interuniversity Microelectronics Center, Kapeldreef 75, B-3001 Leuven, Belgium

^bKatholieke Universiteit Leuven, Celestijnenlaan 200F B-3001, Leuven, Belgium

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].

The use of wet chemical treatments during device processing has proven to be effective and practical for surface damage, contamination and native oxide removal. However, the aggressive downscaling of the transistor in size demands high etching selectivity and control at the nanometer scale, which allows for appropriate III-V surface and interface processing [4,5]. To achieve this goal, a thorough understanding of the interactions between the substrate and the chemical solutions is needed and the basic etching mechanisms need to be resolved. Etching processes that are kinetically controlled are convenient as they allow 3D mass transport effects, which may lead to local enhanced etching, to be minimized.

In this work the etching kinetics of (100) InGaAs is studied for acidic H₂O₂ mixtures (at low pH values (i.e. pH ≤ 3) metallic contamination removal is most effective [6]). GaAs (100) has been included as a reference. The etch rate was determined by measuring the total amount of dissolved III-V materials with Inductively Coupled Plasma – Mass Spectrometry (ICP-MS, Agilent 7500cs). This technique enables detection of substrate loss at sub-monolayer level.

InGaAs is etched in a two-step mechanism. In a first step the semiconductor is chemically oxidized by the H₂O₂ in solution. Subsequently, the formed III-V (hydr)oxides are dissolved by the acid. The influence of the H₂O₂ concentration on the etch rate (v_{etch}) for different HCl concentrations is shown in Figure 1. For 0.1-1M HCl v_{etch} increases linear with increasing H₂O₂ concentration. For 0.01M of HCl v_{etch} levels off at higher H₂O₂ concentration possibly due to a kinetic effect. Figure 2 shows the influence of pH on the v_{etch} for 20 mM H₂O₂. What is striking is that v_{etch} increases with increasing pH value (decreasing HCl concentration) and peaks at pH 2. At higher pH the v_{etch} drops. A comparable trend is observed for GaAs surfaces. The v_{etch} for GaAs is approximately a factor of two lower than that for of InGaAs confirming a higher chemical stability. An v_{etch} in the nm/min range is achieved for 5-10 mM H₂O₂ which is significantly lower than observed for InP [4]. For such low concentrations mass transport effects may become

important. Arrhenius analysis shows this is not the case; the etching of both semiconductors is under full kinetic control (not shown).

References

- [1] International Technology Roadmap for Semiconductors, see www.itrs.net
- [2] M. Heyns and W. Tsai, *MRS Bull.*, **34**, 485 (2009).
- [3] J. A. del Alamo, *Nature*, **479**, 317 (2011).
- [4] D. Cuypers, S. De Gendt, S. Arnauts, K. Paulussen and D.H. van Dorp, *ECS Journal of Solid State Science and Technology*, **2** (4), 185 (2013).
- [5] D.H. van Dorp, D. Cuypers, S. Arnauts, A. Moussa, L. Rodriguez and S. De Gendt, *ECS Journal of Solid State Science and Technology*, **2** (4), 190 (2013).
- [6] K.A. Reinhardt and R.F. Reidy: *Handbook of Cleaning for Semiconductor Manufacturing - fundamentals and applications*, John Wiley and Sons, U.S.A. (2011).

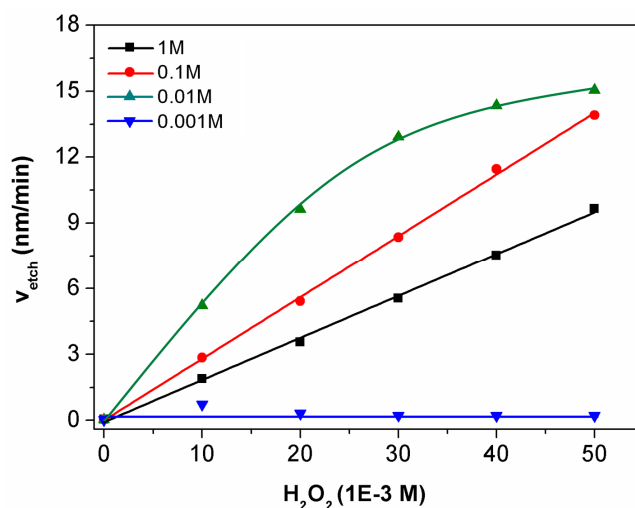


Figure 1: The influence of the H₂O₂ concentration on the chemical etch rate of InGaAs for different HCl concentrations.

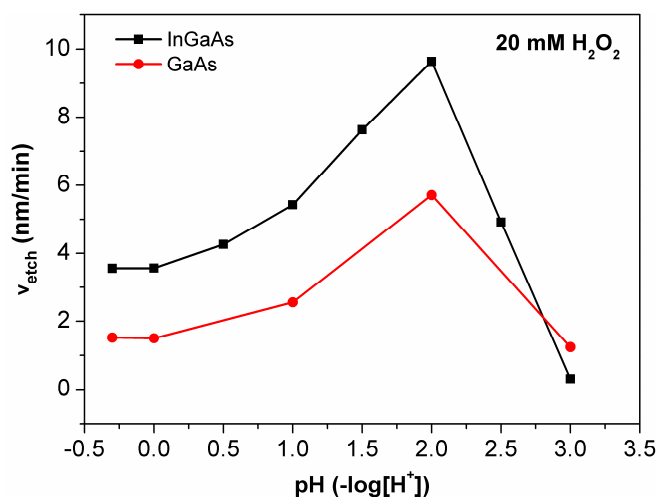


Figure 2: The influence of pH on the chemical etch rate of InGaAs (squares) and GaAs (circles) for 20 mM H₂O₂.