Investigation of Al_2O_3 Deposited by ALD as Passivation Layers for InP-based Nano Lasers

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A good passivation layer is primordial for achieving good performances of deeply etched InP-based nano-lasers. In this paper we have investigated the breakdown voltage of Al_2O_3 deposited by atomic layer deposition (ALD) on InP wafers. A 10-nm thick Al_2O_3 deposited at 300°C shows a uniform breakdown voltage of 6V. ALD-Al_2O_3 can easily be etched in HF-based solution, however dry etching is not trivial. We have investigated dry etching Al_2O_3 in a CHF_3 plasma and found an etch rate of 3.5 nm/min which is acceptable for our applications.

Introduction

Surface passivation is crucial for the performance of semiconductor devices in general and particularly for InP-based semiconductor optical amplifiers (SOAs) and lasers. Surface states originate from the abrupt stop in the crystal lattice at the surface of the semiconductor and also from the oxide layer and adsorbed atoms from environment. Moreover those states with energy levels between the valence and conductance bands form potential recombination centres. The recombination at surface states result in a degradation of the device performance. In electrically pumped nano-lasers like plasmonic lasers [1] the surface to volume ratio is dramatically increasing that an appropriate passivation is of key importance to realise such lasers with high efficiency. Traditionally passivation of Si-solar cells and Si-MOSFETs is done using a dielectric layer like SiN_x or SiO_x. Also in III-V compound semiconductors SiN_x or SiO_x are commonly used for passivation purposes, for instance SiNx is widely used as a passivation layer to eliminate the gate lag in AlGaN HEMTs [2-3]. In InP-based SiN_x or SiO_x are mainly used for masking or for electrical isolation purposes. Passivation of InP-based devices is performed using dip in sulphur-containing solutions like $(NH_4)_2S$ or Na_2S [4-5]. Recently, high-k dielectrics deposited by atomic layer deposition (ALD) show big potential as passivation layers to improve MOSFETS performance and solar cells [6-7] due to the improved breakdown voltage and the lowered leakage currents.

In this work we present our preliminary results investigating the use of an ALD-Al_2O_3 as a passivation layer for plasmonic devices by measuring breakdown voltage as a function of film quality and thickness and through an etching study of this material not only by wet etching in HF-containing solution but also using CHF_3-based reactive ion etching (RIE) process.

Experimental

Al_2O_3 films were deposited in a load-locked remote plasma assisted atomic layer deposition machine FlexAl from Oxford Instruments Plasma Technology. This technique allows monolayer growth control of high quality thin films alternating trimethyl-aluminium, $Al(CH_4)_3$ (TMA) exposure and an ICP (inductively couple plasma) O_2 plasma. Cycles of 20 ms TMA exposure, 1.5 s O_2-purge, 2 s O_2-plasma, 0.5 s plasma purge were repeated till the desired thickness is achieved. The film growth was monitored in situ using spectroscopic ellipsometry. The growth rates are 1.17 Å and 1.05 Å per cycle at 200° and 300°C respectively. In our experiments the duty cycle times of the various Al_2O_3 layers were kept constant.

In the experiments related to measuring the breakdown voltage we have used n-type InP wafers (±5E18 cm^{-3}). These wafers were cleaned using 10 min O_2-plasma followed by a 2-min oxide removal in a 10% H_3PO_4 solution. Immediately after the Al_2O_3 layers were deposited on the InP wafers. Subsequently through an optical lithography step metal contacts pads of 100x100 μm^2 were formed using Ti/Pt/Au metallization (60/75/200 nm) as shown in figure 1. I-V measurements between the metal pad and the backside of the wafer provide the information related to breakdown voltage.

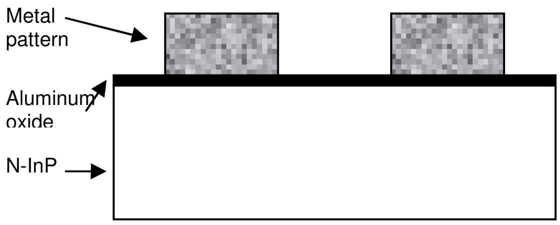

Figure 1: Cross-sectional view of the layers.

In order to determine the etch rate with RIE 50 nm Al_2O_3 is deposited on a plane InP wafer. Using pure CHF_3 plasma at 75 W RF power, Al_2O_3 is etched in steps of 2 min followed by dip in HCl/H_3PO_4 solution to check if Al_2O_3 is completely etched. After 14 min Al_2O_3 is completely etched which corresponds to an etch rate 3.5 nm/min.
Later 1.5 µm deep ridge waveguides are made on InP wafer using a PECVD SiO_x mask. After etching InP, the SiO_x mask is removed in 10% HF solution followed by an ALD deposition of 50nm Al_2O_3.

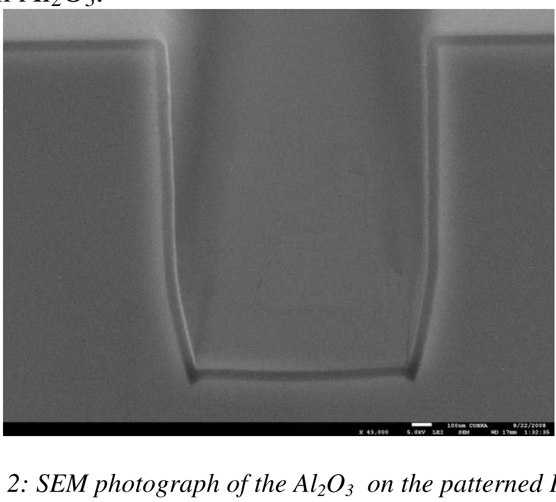

Figure 2: SEM photograph of the Al_2O_3 on the patterned InP wafer.

Figure 2 shows a SEM photograph of the waveguides with the 50nm Al_2O_3. The Al_2O_3 on top surface has to be removed for real devices in order to make contacts whereas side wall should be covered with the passivation layer.

Results and Discussion

Two deposition temperatures of the Al_2O_3 layer were investigated namely 200°C and 300°C. The breakdown voltage measurements show that the layer deposited at 200°C has poor insulating characteristics and quite non-uniform values of breakdown voltage. However as shown in figure 3 the layer deposited at 300°C demonstrates better uniform results with breakdown voltages of more than 5 V.

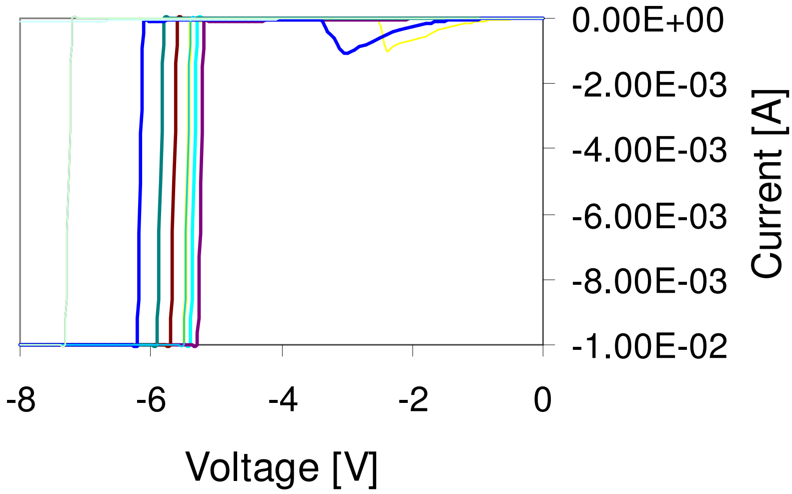

Figure 3: Electrical characterization of the Al_2O_3 deposited at 300°C.

Dry etching was carried out using a pure CHF_3 process in a standard capacitively coupled RIE reactor (50 sccm CHF_3, 15 mTorr, 75 W RF power). Although a fluorine-containing gas is not suitable for etching Al-containing products because of the low volatility of the etching product AlF_3 we have deliberately chosen this chemistry as it is highly selective to InP and also to the used photo-resist. We have found that etching Al_2O_3 is possible and the etching rate of 3.5 nm/min is acceptable as only 10 nm of Al_2O_3 is required for our device applications. Figure 4 shows a SEM photograph after having etched away the Al_2O_3 located at the top and bottom of the ridge as RIE is a directional etch. After Al_2O_3 etch a short dip in 1% HF solution is done to ensure a complete cleaning of the InP top surface. To be noticed that the Al_2O_3 layer on the sides of the ridge shows a good adhesion to the ridge which indicates that it will be possible to use this layer for sidewall passivation.

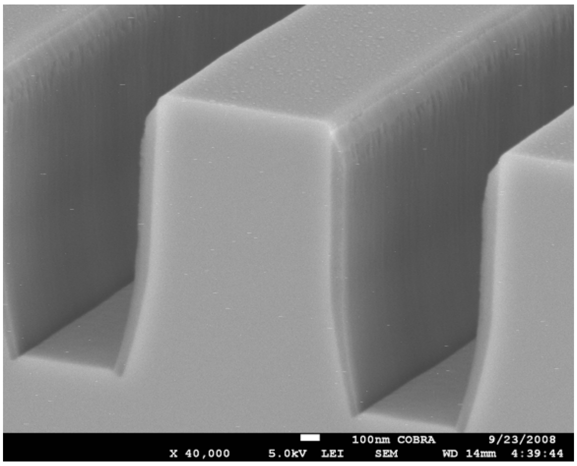

Figure 4: SEM photograph showing a very clean InP surface on top of the ridge with good adhering Al_2O_3 layer on the sidewalls.

Conlcusion

In this paper we have presented our preliminary results on the electrical characterization and on dry etching of ALD-Al_2O_3 layers. A layer 10 nm thick shows a breakdown voltage > 5V and we developed a RIE etching process using CHF_3 chemistry that etches Al_2O_3 at a rate of 3.5 nm/min. The found breakdown voltage and etching rate are sufficient for our envisaged device applications.

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