Effect of LPCVD Si_3N_4 deposition on Al_2O_3 films

Mohammad J. Bereyhi[1]

[1] *Institute of Physics (IPHYS), Swiss Federal Institute of Technology Lausanne (EPFL)*

Alumina (Al_2O_3) films are widely used in photonics and superconducting circuits as an etch stop or passivation layer. In silicon nitride (Si_3N_4) fabrication, a widely used etching recipe is dry etching using a mixture of SF_6/CHF_3 gasses. In case of multi-stacked materials, one might be interested to etch the Si_3N_4 layer with an stop layer to protect the rest of the stack from the etching step. Al_2O_3 is a great etch stop layer for Si_3N_4 etching. Here, we look at the selectivity of the etching process between Si_3N_4 and Al_2O_3 available at EPFL cleanrooms (CMi) using the SPTS dry etching tool. In addition we observe formation of pinholes in the Al_2O_3 film after deposition of LPCVD Si_3N_4 layer. We attribute the pinholes to formation of aluminium oxinitride compounds ($Al_xO_yN_z$). The effect is reduced in lower alumina thickness, but still present. This is a limitation in using alumina as an etch stop for silicon nitride dry etching.

Keywords: Silicon nitride (Si_3N_4); Alumina (Al_2O_3); Dry etching; Etch stop; Integrated Photonics

We use dry etching tool "SPTS" in EPFL cleanroom (CMi), using the "SiN Smooth" recipe that uses a gas mixture of SF_6/CHF_3. The etch rate for Si_3N_4 is load dependent and for our structures are about 200 nm/min. The etch rate for alumina is measured using optical interferometry film measurement tool "FilMetrics". The film thickness that is etched during 30 seconds of etching is shown in figure below:

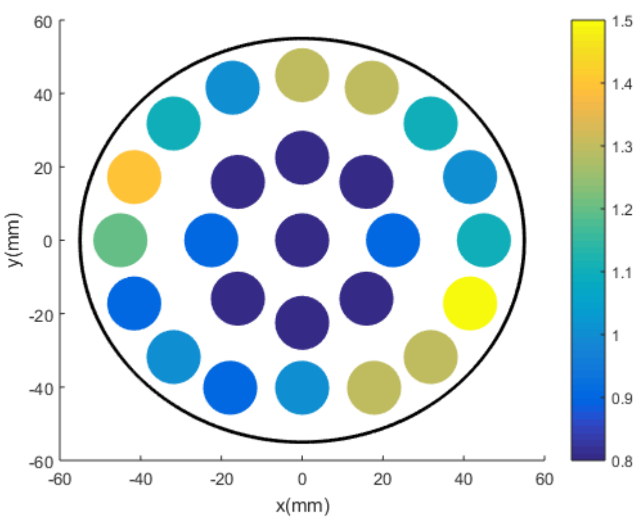

FIG. 1. **Amount of Al_2O_3 etched in 30 seconds using "SiN Smooth" recipe across a 4 inch wafer.** The concluded etch rate for alumina film is < 2 nm/min.

This results in a selectivity of $> 1 : 100$ between $Al_2O_3 : Si_3N_4$. Therefore, only couple of nano meters of alumina is enough for hundreds of nano meters of silicon nitride etching in order to stop the etching from the bottom film stack. Therefore, this layer can be used to stop the etching process for protection of already fabricated photonic or electronic circuits.

This high selectivity is conformed in an etching performed on a stack similar to Fig. 2. The alumina layer is deposited using atomic layer deposition (ALD).

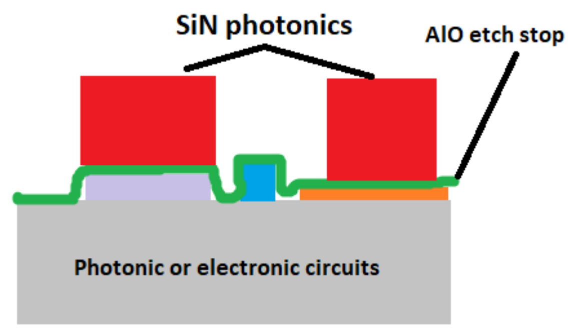

FIG. 2. **Al_2O_3 as an etch stopper for on-top fabrication of Si_3N_4 photonics on a multi-layer stack.**

According to Bermudez et al. (doi.org/10.1116/1.581384) on thin film deposition of PECVD nitride deposition on top of alumina layers, there is a possibility of nitridization of the Al_2O_3 film that can lead to residues. These residues are observed in LPCVD deposition of a silicon nitride layer on top of an alumina layer. This resulted in pinholes and imperfections in the LPCVD deposition.

Depending on the thickness of the Al_2O_3, the density of these pinholes can differ. Lower thicknesses have lower formation of pinholes (Fig. 4). We attribute this effect to a reaction between NH_3 and Al_2O_3 resulting in oxinitride compounds of the aluminum ($Al_xN_yO_z$). The aluminum oxinitride is a ceramic like compound therefore very resistant to cleaning and not easily removed.

The pinhole density is reduced by reduction of the alumina film thickness. These residues are gone for ALD layers of less than 5 nm prior to LPCVD deposition of Si_3N_4(Fig. 4).

This shows a limitation in the usage of alumina etch stop layer to protect the underlying stack while etching the top silicon nitride photonics circuit. Depending on the application, this may affect the process or not.

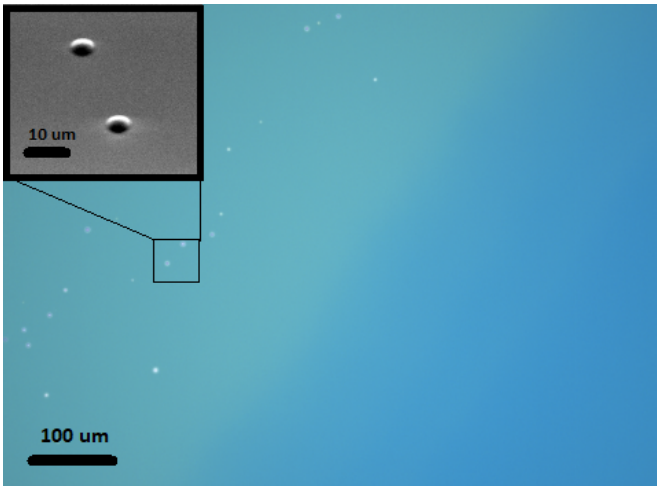

FIG. 3. Al_2O_3 **pinholes caused by LPCVD deposition of** Si_3N_4**.** Pinholes in silicon nitride layer caused by the presence of alumina. The right half of the image shows a region that was masked during alumina deposition and shows pinhole free silicon nitride deposition. The alumina layer is 10 nm and silicon nitride is 250 nm. The inset shows SEM image of one of these pinholes.

The reported nitridization of alumina layer is further confirmed by trying to etch away the etch stop layer after etching the silicon nitride later. In principle the Al_2O_3 layer should be etched away in BOE solution (buffered oxide etch - buffered hydrofluoric acid). However, the alumina layer that has seen the LPCVD furnace environment (high temperature and NH_3 gas) tend to leave residues that were not removed in BOE. This means a chemical reaction on the Al_2O_3 (possible nitridization of the oxide) resulting in a complex compound. This effect has been observed in PECVD silicon nitride deposition in Bermudez et al. (`doi.org/10.1116/1.581384`).

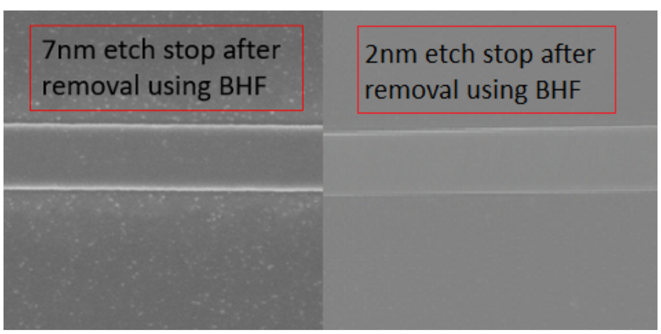

FIG. 4. $Al_xO_yN_z$ **residues depending on the thickness of the alumina stop layer.** The residues of the etch stop layer are significantly lower in thicknesses below 5 nm. The residues are not etched in BOE, therefore are not pure aluminum oxide (Al_2O_3)

Here, we report the possibility of using ALD deposited Al_2O_3 films as an etch stop for Si_3N_4 dry etching in multi-stack photonic circuits using LPCVD deposition. The possible issues with this etch stop technique is also reported as well as its selectivity to silicon nitride etching. This method can be adapted for integrated MEMS fabrication, but with limitations on the top Si_3N_4 film due to pinhole formation in large thicknesses of the etch stop film.