

# Trap Density Analysis of High Dielectric Oxides on III-V Semiconductors

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## Abstract and Introduction:

The prospect of III-V semiconductors offer a higher efficiency alternative to the commonly used silicon, which is currently facing size limitations. One of the major problems surrounding the III-V semiconductors is the high trap density ( $D_{it}$ ) between the oxide and semiconductor interfaces. In this project, metal-oxide-semiconductor capacitors (MOSCAPs) were fabricated using different annealing processes and time frames. Three experiments were conducted on the MOSCAPs for midgap  $D_{it}$  analysis. First, three samples were annealed using forming gas, nitrogen (N), and oxygen (O), respectively. Next, three samples were annealed to 300, 350, and 400°C. Finally, a sample which underwent metal deposition one week after being annealed was compared with a sample with no such time delay. Capacitance-voltage (CV) and conductance-voltage (GV) data was extracted from each sample using the impedance analyzer and manipulated to reveal information about the midgap  $D_{it}$ .

## Experimental Procedure:

The MOSCAP samples were fabricated in several steps. Initially, an  $In_{0.53}Ga_{0.47}As$  substrate was doped with silicon and wet cleaned. The sample was put in the atomic layer deposition (ALD) reactor at 300°C, where it was cleaned for nine cycles with  $N_2$  plasma/TMA, followed by oxide deposition of 35 cycles  $HfO_2$  to the top surface. The sample was then annealed to various temperatures in different gasses. Using the thermal evaporator, Ni was deposited to the top of the sample while Cr and Au were deposited to the bottom.

Both the conductance and Terman methods were used for data analysis, and there are several differences between the two. The conductance method uses only raw data, while the Terman method uses raw and ideal data. The conductance method is most useful at low frequencies (1 kHz), while the Terman method is most useful at high frequencies (1 MHz). Finally, the conductance method shows only the midgap

$D_{it}$ , which is around 0.3 eV, while the Terman method shows a broader range for the trap density.

In this research, however, the Terman method showed results that were either negligible or contradictory to the conductance method, which was considered more reliable since it uses only the raw data. We think this could either have been because of impurities across the interfaces of the samples or because the non-midgap  $D_{it}$  among samples was too close to analyze. For this reason, this paper will only discuss results from the conductance method.

In the first part of the project, we compared samples that were annealed in different gases: forming gas (95% nitrogen, 5% hydrogen), nitrogen and oxygen. Figure 1 shows the raw CV data for the different samples at 1 kHz frequency.

The area of most interest was the midgap bump in the negative bias region. A smaller bump would indicate a lower midgap  $D_{it}$ . Figure 1 shows a lower bump for the oxygen-annealed sample, which would indicate that oxygen is a better annealing gas than forming gas and nitrogen.

Another way to interpret this data is with a  $G_p/w$  3D plot. Shown in Figure 2,  $G_p/w$  is a function of capacitance, conductance, and the natural properties of the sample at every voltage and frequency point. This is useful because the midgap  $D_{it}$  is roughly 2.5 times the peak of this graph. Figure 2 shows the  $G_p/w$  data for the oxygen annealed sample.

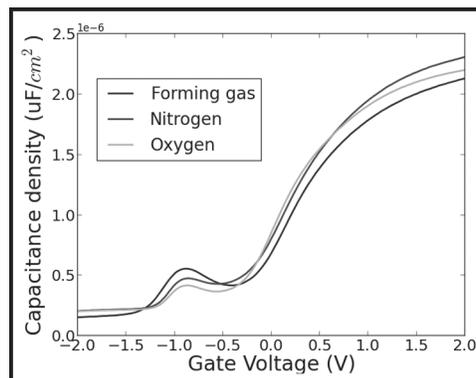


Figure 1: CV curves for samples annealed in different gases.

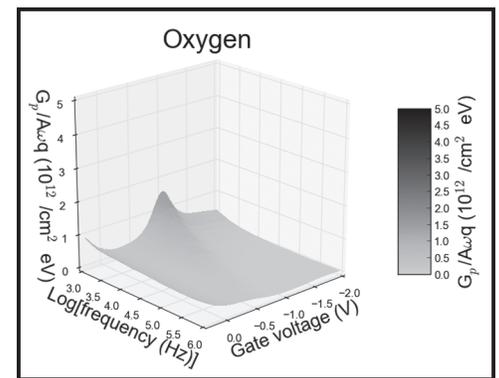


Figure 2: 3D  $G_p/w$  plot for samples annealed in different gases.

While the graphs for the other samples are not shown, the peak for the oxygen annealed sample was in fact lower, which shows that oxygen was in fact a better annealing gas.

In the next part of the project, we varied the annealing temperature, while keeping a constant ramp rate. Figure 3 shows the CV data for the three samples, which were annealed to 300, 350, and 400°C. It is apparent from Figure 3 that the optimal annealing temperature was 400°C. We could see, however, that there was a very small difference between 350 and 400°C, while the sample annealed at 300°C was significantly worse. This led us to believe that since the sample was put in the ALD at 300°C, it was important to anneal it to a higher temperature than that.

In the final part of the project, we compared two samples with the same fabrication parameters, but one sample underwent metal deposition a week after it has been annealed, while in the other metal was deposited on the same day. Figure 4 shows the CV curves for these two samples. There was a vast difference between the two, as it was clear that the smaller bump belongs to the sample that was metal-deposited on the same day. This experiment was important to run because if this discovery hadn't been made, it could have tarnished our other comparisons.

In this project, we noticed a lower midgap  $D_{it}$  in the samples that were annealed in oxygen at high temperatures with gate metal deposited immediately after annealing. We concluded that these were favorable conditions for lowering the trap density in  $HfO_2/n$ -InGaAs MOSCAPS.

There are still many more parameters to test and a great deal more work to be done to achieve a low enough trap density, but our discoveries are a step in the right direction for determining the optimal fabrication process for these devices.

## References:

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- [2] Hwang, Y., Engel-Herbert, R., Rudawski, N.G., and Stemmer, S. Analysis of trap state densities at  $HfO_2/In_{0.53}Ga_{0.47}As$  interfaces. *Appl. Phys. Lett.* 2010;96(10):102910.
- [3] Engel-Herbert, R., Hwang, Y., and Stemmer, S. Quantification of trap densities at dielectric/III-V semiconductor interfaces. *Appl. Phys. Lett.* 2010;97(6):062905.

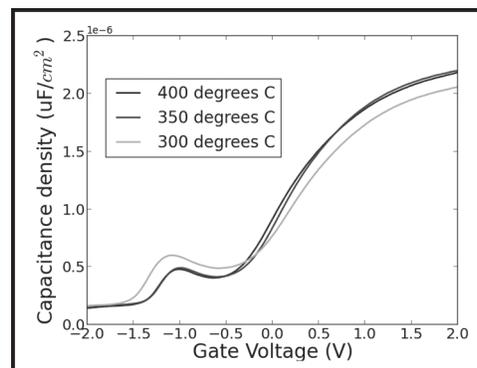


Figure 3: CV curves for samples annealed to different temperatures.

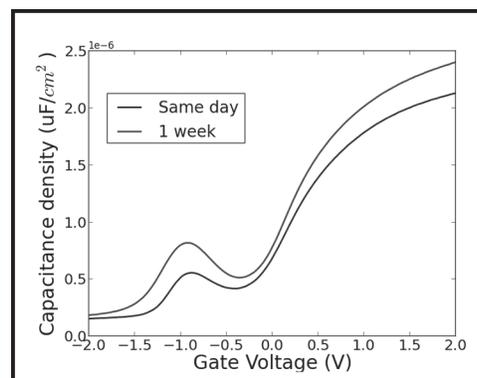


Figure 4: CV curves for samples with different time conditions.