Engineering the Fixed Charge of Aluminum Oxide for Field-Assisted Passivation in Heterojunction Solar Cells

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Abstract:

Surface recombination is a detrimental phenomenon in heterojunction solar cells when electrons recombine with holes at defects in the interface between oxide and silicon. The effects of surface recombination can be reduced through chemical and field-assisted passivation. Chemical techniques improve the actual interface by rendering defects ineffective and are typically achieved through annealing. Field-assisted passivation involves placing a layer of high fixed charge material adjacent to silicon. This charge creates an electric field that attracts opposite charge carriers and repels same charge carriers, reducing carrier interaction with surface defects. In this work, the viability of field-assisted passivation using aluminum oxide (Al_2O_3) is explored by engineering a process that maximizes fixed charge. Different thicknesses of Al_2O_3 are deposited on n- and p-type silicon using plasma-assisted atomic layer deposition and metallized with tungsten or aluminum and titanium nitride. The capacitance-voltage (C-V) characteristics of the resulting structures are measured before and after annealing in forming gas. From the C-V curves, the flat band voltage is derived, and the fixed charge of Al_2O_3 is calculated. From these measurements, Al_2O_3 is found to have a high negative fixed charge, on the order of 10^{12}, indicating that Al_2O_3 has great potential to be used for field-assisted passivation.

Introduction:

Traditionally, solar cells are based on homojunctions formed by n- and p-type silicon. However, there are disadvantages to using this p-n junction. Dark current caused by the potential difference between the two ends of the p-n junction flows counter to the photocurrent and heavy doping in silicon requires high temperatures, increasing production cost.

The newly-proposed heterojunction solar cell involves replacing the p-n junction with hole-selective and electron-selective contacts, NiO and TiO_2 respectively [1]. These selective contacts suppress dark current, by increasing the potential barriers, and require a lower thermal budget, reducing the cost significantly. However, the interface between the passivating oxides and silicon becomes a problem. Interface traps facilitate recombination of electron-hole pairs in a process known as surface recombination, greatly reducing efficiency [1].

Field-assisted passivation is one way to reduce surface recombination. A high fixed charge material is inserted between the carrier selective contact and silicon. This charge creates an electric field that attracts carriers of one type and repels carriers of the other type, reducing carrier interaction with surface defects (Figure 1). In this work, we explore the possibility of using Al_2O_3 as a negative fixed charge material for field-assisted passivation of the hole-selective contacts by quantifying the fixed charge of Al_2O_3.

Experimental Process:

In the experiment, we fabricated a metal-oxide-semiconductor capacitor (MOSCAP) (Figure 2). N-type silicon wafers with a resistivity of 5-10 ohm-centimeters (Ω·cm)

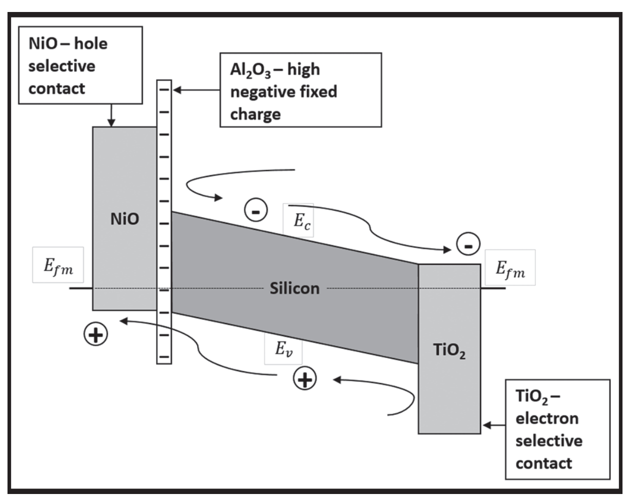

Figure 1: Field-assisted passivation of heterojunction solar cells using Al_2O_3.

and p-type wafers with resistivity of 10-20 Ω·cm were cleaned using standard pre-diffusion RCA clean (SC1-HF-SC2). Al_2O_3 was deposited onto the wafers using plasma-assisted atomic layer deposition (ALD); 250 µm diameter circular metal contacts were sputtered using a shadow mask on the front. Blanket metal was sputtered on the back. Then capacitance-voltage (C-V) measurements were performed from 1 kHz to 1 MHz at a standard Cascade probe station on the sample before and after rapid thermal annealing at 400°C in forming gas (95% N_2 + 5% H_2) for 30 minutes.

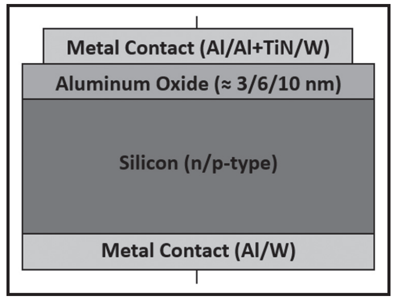

Figure 2: Final fabricated MOSCAP.

We observed that plasma-assisted ALD deposited Al_2O_3 contains high negative fixed charge, making it suitable for field-assisted passivation.

Results and Discussion:

Three main problems were encountered when measuring C-V: noise caused by current leakage, series resistance caused by bad contacts, and frequency dispersion caused by interface traps. Current leakage was minimized by increasing the thickness of the Al_2O_3 layer as well as using non-reactive tungsten as the metal contact. Annealing reduced the amount of series resistance and decreased the number of interface traps, resulting in less frequency dispersion. The C-V curves from our final structures on n- and p-type silicon can be seen in Figures 3 and 4. The fixed charge of Al_2O_3 is calculated by obtaining the oxide capacitance and flat-band voltage shift from the curves. Calculation of fixed charge at the highest and lowest frequencies provides a range for the fixed charge density in Al_2O_3. At 1 kHz, the measured fixed charge for n-type was $^-2.1 \times 10^{13}$ cm^{-2} and for p-type, the fixed charge was $^-4.8 \times 10^{12}$ cm^{-2}. At 1 MHz, the measured fixed charge for n-type was $^-6.8 \times 10^{12}$ cm^{-2} and for p-type, the measured fixed charge was $^-2.5 \times 10^{12}$ cm^{-2}. In general, the negative fixed charge was on the order of 10^{12} cm^{-2}, which is comparable with other measurements of high fixed charge oxides used for field-assisted passivation [2]. Uncertainty in the measurements was caused by frequency dispersion.

Summary and Conclusions:

In this work, we investigated plasma-assisted ALD Al_2O_3 as a source of negative fixed charge for field-assisted passivation. We found ways to reduce noise, frequency dispersion, and series resistance in C-V measurements of the MOSCAP by increasing the thickness of the Al_2O_3, using tungsten contacts, and annealing the samples.

From the C-V curves, Al_2O_3 was found to have negative fixed charge upwards of 10^{12} cm^{-2}, which is suitable for providing field-assisted passivation. The Al_2O_3 ALD recipe will be further optimized to control the amount of fixed charge. Further work will be done to incorporate high fixed charge Al_2O_3 in heterojunction solar cells.

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References:

[1] Islam, Raisul, and Krishna C. Saraswat. "Metal/insulator/semiconductor Carrier Selective Contacts for Photovoltaic Cells." 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC): 285-89.

[2 Werner, Florian, et al. "Very low surface recombination velocities on p-and n-type c-Si by ultrafast spatial atomic layer deposition of aluminum oxide." Applied Physics Letters 97.16 (2010): 162103.

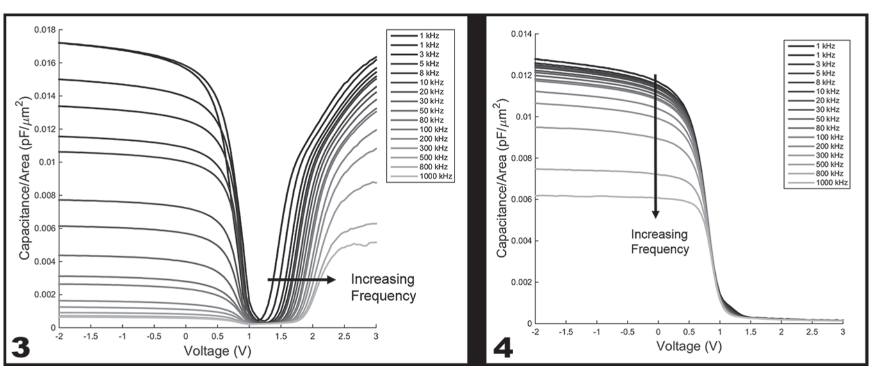

Figure 3, left: C-V plot of final structure on n-type silicon after annealing.
Figure 4, right: C-V plot of final structure on p-type silicon after annealing.