

Non-aqueous Sulfur Solution Passivation for HfO₂/GaSb Metal-Oxide-Semiconductor Capacitors

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Group III-V compound semiconductors have attracted much attention due to their high mobility for advanced CMOS technology. Most III-V materials are suitable for N-type MOSFET application due to their high electron mobility and saturation velocity. However, the low hole mobility limit their using for P-type MOSFET. GaSb has very high electron and hole mobility, making it very suitable for CMOS devices, but high interface trap density (Dit) limits its wide use. In this work, we use non-aqueous sulfur solution for GaSb surface passivation to improve the performance of HfO₂/GaSb MOS capacitors. The results show that surface treatment with sulfur dissolved in acetone (sulfur-acetone solution) has a better effect than that of the (NH₄)₂S aqueous solution.

The substrates used in this study were Te-doped n-GaSb (100) wafers with a doping concentration of $\sim 10^{17}$ cm⁻³. Firstly, the substrates were immersed in acetone, ethanol, and isopropanol for 5 min each to degrease, and then etched with 9% HCl for 1 min to remove the native oxide layer. Then, GaSb substrates were subjected to the $\sim 2\%$ sulfur-acetone solution (sulfur-acetone sample) for 15 min. Control samples were treated with 20% (NH₄)₂S aqueous solution ((NH₄)₂S sample). After that, HfO₂ (~ 5 nm) films were deposited via ALD (atomic-layer-deposition) process using Tetrakis(ethylmethylamino)hafnium (TEMAH) and water as precursors at 200 °C. Al was electron beam evaporated as the gate electrodes. The back-side contacts were formed using Ti/Au. The surface chemical properties were investigated by X-ray photoelectron spectroscopy (XPS) using the Thermo Scientific ESCALAB 205 Xi XPS system equipped with an Al K α source. Capacitance-voltage (C-V), conductance-voltage (G-V), and current-voltage (I-V) measurements were recorded using an Agilent B1500A Semiconductor Device Analyzer and the Cascade Summit 11000 AP Probe System.

Fig. 1 and Fig. 2 show Sb 3d_{3/2} and Ga 3d core level spectra of the sulfur-acetone sample and (NH₄)₂S sample. The reduced area of Sb-O and Ga-O feature indicate that the oxide layer between GaSb and HfO₂ is reduced. The binding energy of Sb-O shifts towards smaller binding energy, which illustrates that Sb-S bond is formed. This is because the electronegativity of S is smaller than that of O. Fig. 3 shows the high frequency (100 kHz) C-V characteristics of those samples. The smaller C_{ox} of sulfur-acetone sample may due to the formation of sulfur layer. The sulfur-acetone sample exhibits an average of ~ 2 orders lower gate leakage current density than that of the (NH₄)₂S sample (see Fig. 4). Typical measured parallel conductance divided by ω (Gp/ ω) versus frequency characteristics for different gate bias values of the sulfur-acetone sample was showed in Fig. 5. The peak shift indicates the Fermi level unpinning over the energy gap. Fig. 6 shows the Dit distribution which is calculated by conduction method. For sulfur-acetone sample, Dit is reduced by 23% compared to the (NH₄)₂S sample, which indicates the sulfur-acetone treatment can reduce dangling bonds.

In conclusion, the sulfur-acetone treatment can reduce the leakage, lower the Dit compared with the (NH₄)₂S treatment. Therefore, sulfur-acetone treatment is a promising method to improve performance of GaSb MOS devices.

Acknowledgments

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References

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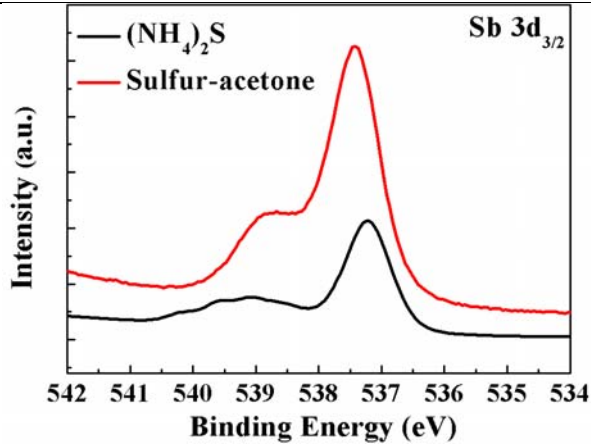


Fig. 1. XPS Sb 3d_{3/2} spectra of GaSb MOSCAPs passivated with sulfur-acetone solutions and (NH₄)₂S solutions.

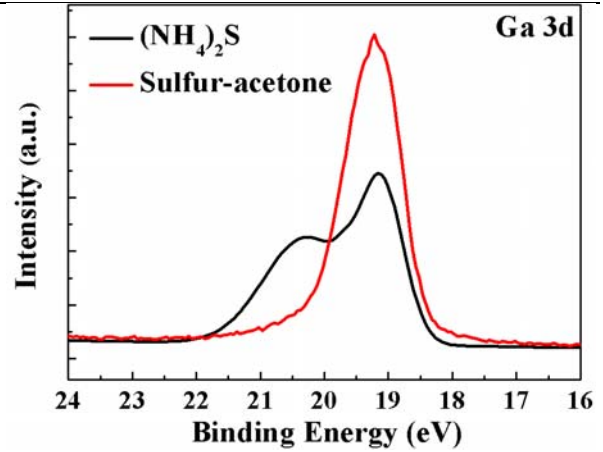


Fig. 2. XPS Ga 3d spectra of GaSb MOSCAPs passivated with sulfur-acetone solutions and (NH₄)₂S solutions.

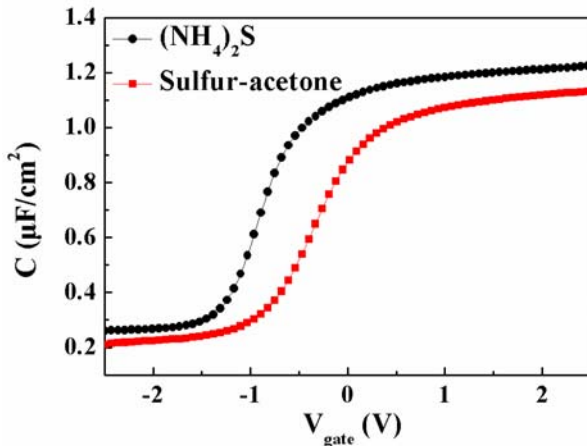


Fig. 3. High-frequency C-V characteristics of GaSb MOSCAPs passivated with sulfur-acetone solutions and (NH₄)₂S solutions.

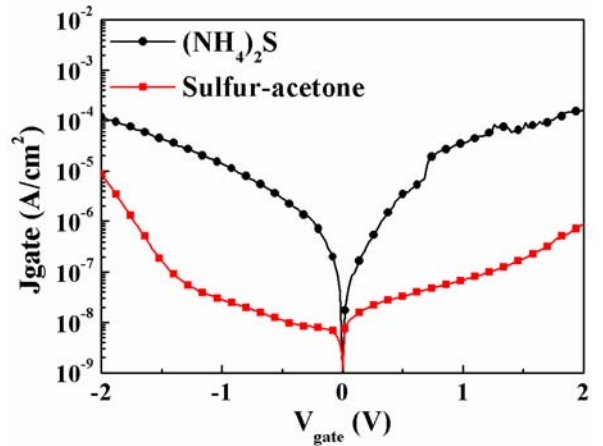


Fig. 4. Gate leakage current of MOSCAPs passivated with sulfur-acetone solutions and (NH₄)₂S solutions.

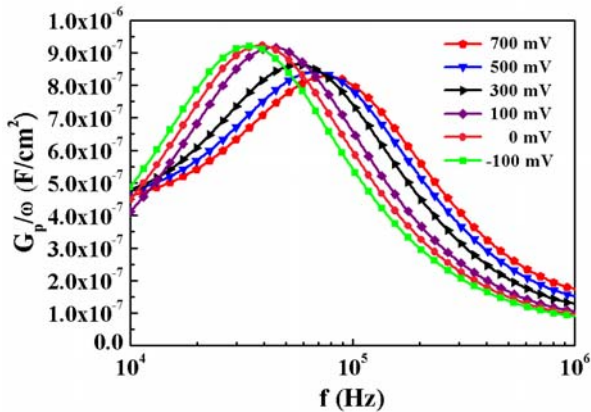


Fig. 5. Typical measured parallel G_p/ω versus frequency characteristics for different gate bias voltages of sulfur-acetone sample.

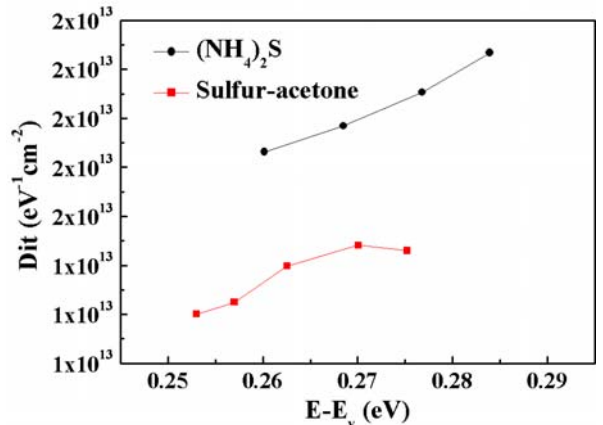


Fig. 6. Dit distributions of MOSCAPs passivated with sulfur-acetone solutions and (NH₄)₂S solutions.