Polycrystalline diamond and high-κ dielectric films for MOS devices

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Motivation

Microelectronic trends are a direct response to rapidly advancing technologies, which push the limits of information technology, global connectivity, unbounded exploration and unquestionable reliability. The expected performance of electronic devices are greater than they have ever been, and thus burgeoned into investigations capable of raising to such demands. Especially pertinent to the performance of metal oxide semiconductor (MOS) devices, are two materials, high-κ dielectrics and ultra-wide band gap (UWBG) semiconductors. As more components are placed on circuit boards to facilitate the numerous system operations, the size of each device is greatly reduced necessitating exploration into more suitable options, such as high-κ films, in transistors and capacitors to effectively control semiconductor charge carriers and prevent charge leakage. In addition, UWBG semiconductors such as diamond efficiently permit device operation in harsh and extreme conditions, high temperature and high power applications. Polycrystalline diamond (PCD) is an UWBG material that provides a cost effective option for MOS devices, but it has yet to be fully studied for these applications. In concert, these two films can be optimized to meet the demands of microelectronic device performance.

Objective

PCD B-doped films are grown by hot filament chemical vapour deposition (HFCVD), with conditions optimized for low resistivity. High-κ Al2O3, TiO2 and Ta2O5 films are deposited by atomic layer deposition (ALD) on PCD surfaces. Together in MOS structures their electronic properties are characterized.

Diamond Film Growth and Optimization

Figure 1: Schematic of a general MOS field effect transistor (MOSFET) demonstrating the position of the high-κ gate or metal oxide film on the semiconductor doped PCD surface.

Figure 2: HFCVD reaction for growth of B-doped films on Si. Film optimization is investigated through the parameters:
- B concentration
- CH4 concentration
- Si surface pre-treatments
- application of a voltage bias

Table 1: Diamond surface structure; grain size correlates positively with film thickness

<table>
<thead>
<tr>
<th>B/CH4</th>
<th>1.67E-04</th>
<th>3.33E-04</th>
<th>8.33E-04</th>
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<tbody>
<tr>
<td>No bias V</td>
<td><img src="image1.png" alt="image" /></td>
<td><img src="image2.png" alt="image" /></td>
<td><img src="image3.png" alt="image" /></td>
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<tr>
<td>Bias 170 V</td>
<td><img src="image4.png" alt="image" /></td>
<td><img src="image5.png" alt="image" /></td>
<td><img src="image6.png" alt="image" /></td>
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Figure 3: Diamond film resistivity determined from IV measurements demonstrate the influence of the various parameters on the sheet resistivity. Resistivity is thus dependent on the B and CH4 concentrations, application of a voltage bias, and pre-treatment (NT – no treatment; T – treatments). The dependence does not seem to be linear. The chart shows resistivity by height of the individual colours.

High-κ Films by ALD on Polycrystalline Diamond

Figure 4: Al2O3 films on PCD deposited by ALD according to the cycle above. SEM micrograph (left) showing cross-sectional view of Al2O3 on the PCD surface and EDS mapping (right).

Figure 5: TiO2 film deposited by ALD on a PCD film surface using tetrakis(dimethylamino) Ti (TDMAT) and H2O as Ti and O precursors, respectively.

Mechanical and chemical interfacial quality of the diamond and ALD oxide can be investigated by nanoindentation analysis and XPS, respectively, while electrical interfacial quality can be achieved via capacitance measurements.

References


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