Diamond:H/Transition Metal Oxides Transfer-Doping: Efficiency and Transistor Performance

Dr. Moshe Tordjman

Prof. Jesus A. del Alamo
Dr. Alon Vardi
Dr. Zongyou Yin
Dr. Youngtack Lee

Prof. Rafi Kalish

Technion
Israel Institute of Technology

MTL
microsystems technology laboratories
massachusetts institute of technology
Diamond Surface Transfer Doping with Adsorbates Molecules

**Drawbacks:**
1. Volatile and Sensitive to Atmospheric Fluctuations.
2. No Temperature Stability.
3. Low Work Function → Limited conductivity

Diamond Surface Transfer Doping with Transition Metal Oxides

Advantages:
1. Temperature Stability (up to 350-450°C).

TMOs Surface Acceptors:

Diamond:H/TMO Transfer Doping

TMOs come into Various:
1. Crystallization Structures.
2. Oxidation phases. (i.e. MoO$_{3-x}$, V$_2$O$_{5-x}$, WO$_{3-x}$ etc.)
3. Coverage Uniformity.

MoO$_3$ Thermal Evaporation Integrity to FET Fabrication Process

Challenges:
1. Nonhomogeneous Morphology.
3. Carrier Loss due to band-energy Misalignment.

Vardi et.al. EDL 35,12 (2014)
ALD MoO$_3$ Surface Acceptor

**ALD 170°C: Mo(CO)$_6$ / O$_3$ → MoO$_3$**

- Roughness Quality improved.
  1. Electronic Gap States - reducing WF.

$Ra=0.36\text{nm}$

ALD HyMoO$_3$ Surface Acceptor

ALD $350\,^\circ C$: $C_{12}H_{20}MoN_4 / H_2O \rightarrow H_yMoO_3$

ALD H₄MoO₃ Surface Acceptor

ALD 350 °C: C₁₂H₂₀MoN₄/H₂O → H₄MoO₃

Ra=0.30nm

Hydrogen Incorporation Contributes:
1. Strengthen Covalent bonds. → No O Reduction.
   → No Work Function Degradation.
2. Improved Surface Roughness Quality.
   ➢ What about Energy- Band Alignment?

Diamond:H/MoO$_3$ Vs. H$_y$MoO$_3$ Properties

- High Budget Temp. FET Fab. Process
- S/D Contacts E-Beam
- HfO$_2$ – Oxide gates ALD 150°C + RTA 600°C
- Top gate + Channel isolation

Diamond:H/MoO₃ Vs. HₓMoO₃ FETs

<table>
<thead>
<tr>
<th>Configuration</th>
<th>FET completed device - Post-process fabrication</th>
<th>Hall pre-processed structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured parameters</td>
<td>Hole mobility (cm²/V·s)</td>
<td>Hole concentration (cm⁻²)</td>
</tr>
<tr>
<td>Diamond:H/MoO₃</td>
<td>1.7</td>
<td>3.2 × 10¹²</td>
</tr>
<tr>
<td>Diamond:H/HₓMoO₃ₓ</td>
<td>20.2</td>
<td>5.1 × 10¹²</td>
</tr>
</tbody>
</table>

MoO$_3$ Vs. H$_y$MoO$_3$ Band-Energy Alignment

MoO$_3$ Vs. H$_y$MoO$_3$ Band-Energy Alignment

Conclusions

- A Novel Advantageous Surface Acceptor: $H_yTMO$
- General Strategy for Integrating and Modulating Electronic States in $H_yTMO$.
- **Diamond:**$H/H_yMoO_3$ Surface Acceptor shows:
  1. Improved Morphology Smoothness.
  2. Immunity to Harsh Processing FET Fab.
  3. Improved Cross-Transport via band-energy alignment.

Thank YoU