10-12-2018

Characterization of Electron Yield Suppression with Carbon Nanotube Forest Grown on Silicon Substrates

Brian Wood
Utah State University

Jordan Lee
Utah State University

Justin Christensen
Utah State University

Gregory Wilson
Utah State University

JR Dennison
Utah State University

T. -C. Shen
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/mp_presentations

Part of the Condensed Matter Physics Commons

Recommended Citation
Wood, Brian; Lee, Jordan; Christensen, Justin; Wilson, Gregory; Dennison, JR; and Shen, T. -C., "Characterization of Electron Yield Suppression with Carbon Nanotube Forest Grown on Silicon Substrates" (2018). Fall 2018 Four Corner Section Meeting of the American Physical Society. Presentations. Paper 176.
https://digitalcommons.usu.edu/mp_presentations/176

This Presentation is brought to you for free and open access by the Materials Physics at DigitalCommons@USU. It has been accepted for inclusion in Presentations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
Characterization of Electron Yield Suppression with Carbon Nanotube Forests Grown on Silicon Substrates

Brian Wood, Jordan Lee, Justin Christensen, Greg Wilson, JR Dennison, T.C. Shen
Utah State University
Injection CVD and SEM Characterization

High Density 0.5% Ferrocene

Low Density 0.2% Ferrocene

Xylene: $C_6H_4(C_5H_3)_2$

Ferroocene: $Fe(C_5H_5)_2$

$R(E_0)$

Height

$26 \mu m$
Secondary Electron Yield

\[ \delta = \frac{Q_{\text{Secondary}}}{Q_{\text{Incident}}} \]

Schematic of the Hemispherical Grid and the Biasing during data collection
Between 100-10,000 eV, SEY of AlSi substrate ~ 18% higher than bare Si

Multilayer Effects

CNT Forest NOT a direct combination of substrate yield and carbon yield

\[ R(E_0) \]
**CNT Morphology vs Bulk Material**

**Mass Density**

- HOPG $\sim 2.2 \, g/cm^3$
- CNTF’s $\sim 0.07 \, g/cm^3$

---

![Graph of Electron Yield vs Incident Electron Energy](image)

- $\sigma_{\text{CNT}} < \sigma_{\text{HOPG}}$ for $E \leq 500 \, eV$
- $\sigma_{\text{CNT}}$ starts to converge with AlSi Substrate higher energies
- Density not the only factor dictating penetration depth
Comparison of Secondary Yield Results

- CNT yield suppression viable up to 1 keV
- Yield of forests actually higher than substrate above 1 keV

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>CNT Forest Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Height (µm)</td>
</tr>
<tr>
<td>AISi 127</td>
<td>24-27</td>
</tr>
<tr>
<td>AISi 129</td>
<td>42-51</td>
</tr>
<tr>
<td>AISi 132</td>
<td>27-32</td>
</tr>
</tbody>
</table>
Conclusions

- Carbon nanotube forests lowered secondary yield of substrate up to 1 keV incident energy
- Explanation of sample’s yield cannot be explained serially
- Forest height main factor in reducing yield

Acknowledgments

- T.C. Shen and Nano Device Lab
- Utah State Microscopy Core Facility
- Utah State Material Physics Group
Comparison of Backscatter Yield Results

- CNT forests have lowest BSEY, especially in the lower energy range
- CNT BSEY has similar shape as substrate
- CNT BSEY starts to match HOPG in higher energies
Data Acquisition

\[ \sigma = \frac{Q_{\text{Secondary}} + Q_{\text{backscatter}}}{Q_{\text{Incident}}} = \frac{\int (I_{\text{coll}} + I_{\text{grid}} + I_{\text{stage}})/\Gamma_{\text{HGRFA}} \, dt}{\int [(I_{\text{coll}} + I_{\text{grid}} + I_{\text{stage}})/\Gamma_{\text{HGRFA}} + I_{\text{sample}}] \, dt} \]
• AlSi 127 and AlSi 132 almost identical secondary peak
• Taller forest has greatest secondary electron suppression ability

• AlSi 129 backscatter peak ~27% less than substrate, consistent with backscatter yield results
• Backscatter peak absent for AlSi 127 and AlSi 132 due to large secondary peak
HOPG vs AlSi 129

HOPG Yield

$E_{max} = 200 \text{ eV}$  
Max Yield = 1.34

$E_1 = 45 \text{ eV}$  
$E_2 = 500 \text{ eV}$

AlSi 129 Electron Yield

$E_{max} = 1000 \text{ eV}$  
Max Yield = 1.06

$E_1 = 550 \text{ eV}$  
$E_2 = 1400 \text{ eV}$
Density

HOPG ~ \(2.2 \, \text{g/cm}^3\)

CNTF’s ~ \(0.2 \, \text{g/cm}^3\)

Graphite Roughly \(\times 10\) Denser than Carbon Nanotubes

Graphite Roughly \(\times 10-100\) Denser than Carbon Nanotubes
Electron Emission Overview Cont’d

**Total Electron Yield**

\[ \sigma = \frac{Q_{\text{Secondary}} + Q_{\text{Backscatter}}}{Q_{\text{Incident}}} \]

**Secondary Electron Yield**

\[ \delta = \frac{Q_{\text{Secondary}}}{Q_{\text{Incident}}} \]

**Backscatter Electron Yield**

\[ \eta = \frac{Q_{\text{Backscatter}}}{Q_{\text{Incident}}} \]

Energy Spectrum of Emitted Electrons

Crossover Energies

Total Yield Results of Gold
CNT Morphology vs Bulk Material

HOPG

21 nm

3 µm

Carbon Nanotube Forest
\[ \sigma = \frac{Q_{\text{Secondary}} + Q_{\text{backscatter}}}{Q_{\text{Total}}} = \frac{\int I_{\text{out}} dt}{\int I_{\text{in}} dt} = \frac{\int \left( \frac{I_{\text{coll}} + I_{\text{grid}} + I_{\text{stage}}}{\Gamma_{\text{HGRFA}}} \right) dt}{\int \left[ \left( \frac{I_{\text{coll}} + I_{\text{grid}} + I_{\text{stage}}}{\Gamma_{\text{HGRFA}}} \right) + I_{\text{sample}} \right] dt} \]
Stopping Power and Penetration Depth

\[- \frac{dE}{dz} = A \frac{1}{E^{n-1}}\]

Secondary Electron Generation

\[n(E_0) = \frac{1}{\epsilon_m} \frac{dE}{dz}\]

Production Energy \(\uparrow\)

Emission Probability

\[P(z) = \beta \cdot \alpha \cdot e^{-\frac{z}{\lambda}}\] \(\text{Mean Free Path}\)

Escape Probability \(\uparrow\)

Geometrical Factor
Total Electron yield of the carbon nanotube forest versus HOPG, a carbon fiber mesh, and aluminum.

- CNT has lower total yield right till 700 and 1000 eV for HOPG and M55J respectively.
- Again, similar shape with HOPG but $E_{max}$ happening at a larger energy.