Electron Beam Induced Deposition and Etching Research
**Applications**
- DEAL—Parallel electron beam lithography
- Nanoscale Device Rapid Prototyping
  - Electrical
  - Optical
  - Biological
  - Micro Electro Mechanical
- Nanoscale Repair
  - Chip Repair
  - Lithography Mask Repair
  - High Information Content CD Masters

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UTK EBIP Research
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Parallel ebeam lithography system (DEAL)

Dielectric: SiO₂
Emitter: EBID Tungsten
Gate: Molybdenum

 Beam Heating Simulation

F = 90 kV
Bulk Fiber Disposition
Quasi-One-Dimensional Fiber Disposition

SBID Characterization

EBID lithography

S
M
O
Si₂
Resist
Nanofiber
W

Exposure
0.11 nA 2.38 nA

Develop
0° 0°
40° 40°

Etch
60° 60°
Nanoscale Device Processing

EBID Field Emission Device

Si

Mo

SiO₂

Resist

W Nanofiber

Gate: Molybdenum

Dielectric: SiO₂

Emitter: EBID Tungsten

500 nm
Rack Group EBID/E Simulation

- 3D model
- PE/BSE/FSE/SE tracking
- 3D surface diffusion
- Stationary or rastered beam, (shows effects of varying dwell time, refresh times, etc.)
- Sub-program to estimate localized gas pressure
- Multi-material geometric features
- Deposition and Etching
Primary Electron Deposition (PE)

Forward Scattered (FSE)

Secondary Electrons (SE)

Back Scattered (BSE)

FSE into Substrate
**Simulation “Q-test”**

**Primary EBID Test**
Gas present at pixel? – **yes** (do Q-test)

\[
Q_{PE} = \frac{\sigma(E_{PE}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}
\]

\[\text{rand < Q? – **yes** (deposit PE atom)}\]

**SE EbID Test**
Gas present at pixel? – **yes** (do Q-test)

\[
Q_{SEI} = \frac{\sigma(E_{SEI}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}
\]

\[\text{rand < Q? – **yes** (deposit SE atom)}\]

**SEII EbID Test**
Gas present at pixel? – **no** (no Q-test)

**BSE EbID Test**
Gas present at pixel? – **yes** (do Q-test)

\[
Q_{BSE} = \frac{\sigma(E_{BSE}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}
\]

\[\text{rand > Q? – **no** (no BSE atom)}\]
3x3 rastered beam simulation
Pressure Simulator

- Input Variables
  - EITHER:
    - Flow rate of precursor gas, OR Ion Gauge Pressure and \( \text{Seff} \)
  - Precursor Temperature
  - Precursor Molecular Weight
- Geometry Factors:
  - Outer nozzle radius
  - Inner nozzle radius
  - Substrate clearance
  - Nozzle tilt angle
  - Gas spread angle

![Diagram of nozzle and gas spread angle](image)

- \( r_a \): outer radius
- \( r_i \): inner radius
- \( a \): clearance to the substrate
- \( d \): clearance to the e-beam
- \( \beta \): spread angle
- \( \alpha \): nozzle angle
- \( l \): nozzle length

gas covered region (A)
Enhancement vs height (Tilt angle fixed at 76.64°) Temp=273°K
Spread Angle varied from 10 to 40°
EBID Characterization

As-Deposited  Post-Sputter Profile

SEM and Element Maps of EBID Tungsten Before and After Sputter-Depth Profile

- Tungsten
- Silicon
- Oxygen

Atomic Concentration (%) vs. Distance (10 nm)

5500 pA  200 pA  70 pA

20 nm  20 nm  20 nm

20 nm  5 nm  20 nm
Field Emission Devices

- Si
- Mo
- SiO₂
- Resist
- W Nanofiber

(a) Si
(b) Mo
(c) SiO₂
(d) Resist
(e) W Nanofiber

Graph showing Measured Anode Current (nA) vs. Cathode Bias (V)

Image showing structures labeled as Si, Mo, SiO₂, Resist, and W Nanofiber.
EBID Heating Simulation

Monte-Carlo Single Scattering Model

Energy Deposition Profile

Finite Element Thermal Model

Graph:
- E = 20 keV
- I = 500 pA
- D = 100 nm

Graph shows:
- Bulk Heat Dissipation
- Quasi-One-Dimensional Heat Dissipation

Graph axes:
- Surface Temperature (K)
- Nanofiber Height (nm)

Diagram:
- Insulated Boundary
- 530 nm
- 2000 nm
- 300 K Boundary
- EBID SiO₂
- Tungsten
- PECVD SiO₂
Temperature Dependent EBID

- Growth Height at 25°C
- Growth Height at 40°C

\[
\ln \left( \frac{h(T)}{h_0} \right) = \frac{E_a}{kT} - \ln \left( h_0 \right)
\]

- \( E_a = 0.226 \pm 0.03 \text{ eV} \)
- \( h_0^* = 3.62 \times 10^{-5} \text{ nm/sec} \)
Electron Beam Induced Etching
EBID Nanoscale Lithography
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