Fabrication of micrometer-sized conical field emitters using femtosecond laser-assisted etching of silicon

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irradiate with 100-fs 10 kJ/m² pulses
Introduction

“black silicon”
Introduction

20 µm
Introduction
Introduction
Background

Absorptance
Background

absorptance

Background

absorptance

Background

Absorptance

Background

Points to keep in mind:

- one-step, maskless process
- large area with uniform high density of spikes
- band structure change
gold coating
Setup

20 µm mica spacers

gold coating
Setup

anode

gold coating
Setup

Diagram showing an anode with a gold coating connected to a 1 MΩ resistor and a voltage source. A voltmeter (V) and ammeter (A) are also shown in the circuit.
Results
turn-on field (1 µA/cm²): 1.2 V/µm
Results

threshold field (10 $\mu$A/cm$^2$): 2.1 V/µm
Results
Results
Results
Results

![Graph showing the relationship between potential difference (V) and current (mA)]
Results

maximum current: 15 mA (4 mm$^2$ sample)
Results
Results
Discussion

Ion channeling and electron backscattering

- spikes retain crystalline order
- high density of defects
Secondary ion mass spectrometry:

- $10^{20}$ cm$^{-3}$ sulfur
- $10^{17}$ cm$^{-3}$ fluorine
sulfur introduces states in the gap

states broaden into a band
Field emission

$E_F$

$E_g$

CB

VB

semiconductor vacuum

$\phi$

\[ \text{SLIDE HEADING} \]

\[ \text{semiconductor vacuum} \]
Field emission

The diagram illustrates the energy bands of a semiconductor in the presence of a vacuum. The conduction band (CB) and the valence band (VB) are marked with $E_F$ and $E_g$, respectively. The work function $\phi$ represents the energy difference between the Fermi level $E_F$ and the vacuum level in the semiconductor. The diagram highlights the transition from the semiconductor to the vacuum.
Field emission

- CB: Conduction Band
- VB: Valence Band
- $E_F$: Fermi Level
- $E_g$: Band Gap
- $\phi$: Work Function
- $e^{-}$: Electron
Field emission

- CB
- $E_F$
- VB
- semiconductor
- vacuum
- $e^-$
Discussion
sulfur band provides additional electrons
Microstructured silicon

- fabricated by simple, maskless process
Microstructured silicon

- fabricated by simple, maskless process
- can be integrated with microelectronics
Microstructured silicon

- fabricated by simple, maskless process
- can be integrated with microelectronics
- provides stable, high field-emission current
Microstructured silicon

- fabricated by simple, maskless process
- can be integrated with microelectronics
- provides stable, high field-emission current
- is durable
Future Directions

- Ordered arrays
- Other gases
- Functionalizing
- Emission mechanism
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http://mazur-www.harvard.edu