BLACK SILICON:
hot properties and many open questions

Eric Mazur
Jim Carey
Catherine Crouch
Rebecca Younkin

ITAMP Workshop
Cambridge, 14 June 2001
introduction

irradiate with 100-fs 10 kJ/m² pulses
Introduction

“black silicon”
Introduction
Introduction
Background

absorptance

![Graph showing absorptance vs wavelength for crystalline silicon](image-url)
Background

absorptance

Background

absorptance

Background

**absorptance**

![Graph showing absorptance vs wavelength for microstructured and crystalline silicon.](image)

Background

Points to keep in mind:

- one-step, maskless process
- large area with uniform high density of spikes
- band structure change
Field emission

![Diagram showing metal and vacuum with $E_F$ and $\phi$]
Field emission

\( E_F \)

\( \phi \)

metal vacuum
$E_F$

metal

vacuum
Field emission

\[ E_F \]

metal \hspace{1cm} vacuum

\[ \phi \]

\[ e^- \]
Field emission

\[ E_F \]

\[ E_g \]

\[ \phi \]

semiconductor

vacuum

VB

CB
Field emission

- Semiconductor
- Vacuum
- CB
- VB
- $E_F$
- $E_g$
- $\phi$
Field emission

\[ E_F \quad \text{CB} \quad \phi \quad E_g \quad \text{VB} \quad e^- \]

semiconductor \quad vacuum
Field emission

- Semiconductor
- Vacuum
- CB (Conduction Band)
- VB (Valence Band)
- $E_F$ (Fermi Level)
- $e^-$ (Electron)

Diagram showing the energy bands and the process of field emission from the semiconductor to the vacuum.
Field emission

- CB
- VB
- $E_F$
- $e^-$
- Semiconductor
- Vacuum
Field emission

\[ \ln \frac{I}{\Delta V^2} = \ln a - b \frac{1}{\Delta V} \]

Setup
gold coating
20 µm mica spacers
gold coating
Setup

anode

gold coating
Setup

- **anode**
- **gold coating**
- **1 MΩ**
- Voltmeter (V)
- Ammeter (A)
Results
Results

turn-on field (1 µA/cm$^2$): 1.3 V/µm
threshold field (10 $\mu$A/cm$^2$): 2.15 V/$\mu$m
Results
Results
Results
Results

![Graph showing the relationship between potential difference (V) and current (mA). The graph indicates a linear relationship with increasing potential difference leading to an increase in current.]
Results

maximum current: 2 mA (4 mm$^2$ sample)
Results
Results
Space charge effect

Space charge effect

Space charge effect

Space charge effect

\[ \Delta V \]

\[ x \]

Y.Y. Lau et al., *Phys. Plasmas* 1, 2082 (1994)
Space charge effect

Space charge effect

Space charge effect

Space charge effect

Space charge effect

Space charge effect

\[ I \propto \frac{V}{Z + R} \]

Space charge effect

\[ I \propto \frac{V}{R} \]

Y.Y. Lau et al., *Phys. Plasmas* 1, 2082 (1994)
Space charge effect

![Graph showing the relationship between potential difference (V) and current (A) with a 1 MΩ reference line.](image)
Space charge effect

![Graph showing the relationship between potential difference (V) and current (A) with potential difference in the x-axis ranging from $10^1$ to $10^4$ and current in the y-axis ranging from $10^{-6}$ to $10^{-1}$. The graph includes curves for potential differences of 0.5 MΩ and 1 MΩ.]
Outline

- Background
- 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
**Discussion**

sulfur introduces states in the gap

<table>
<thead>
<tr>
<th>VB</th>
<th>CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.614 eV</td>
<td>0.371 eV</td>
</tr>
<tr>
<td>0.318 eV</td>
<td>0.188 eV</td>
</tr>
<tr>
<td>0.11 eV</td>
<td>0.09 eV</td>
</tr>
<tr>
<td>0.08 eV</td>
<td>0.248 eV</td>
</tr>
</tbody>
</table>

states broaden into a band
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
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- provides stable, high field-emission current
Summary

Microstructured silicon

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

New Scientist 13, 34 (2001)

A forest of silicon spikes could revolutionise solar cells and give you painless injections. Bruce Schechter peers into the mysterious world of black silicon

TALL, DARK AND STRANGER

WE ALL love stories of serendipity. They allow us to hark back to a time when a fogged window or a filthy Petri dish revealed the secret of the universe. And so it was in 1996 when Professor Mark Mazur at the University of Florida and his grad student Allon Dromi announced they had created the first light-emitting diode (LED) based on silicon. It was an extraordinary moment, and although their invention was not immediately obvious, it is now having an impact on the world of electronics.
Applications

- display technology
- detector technology
- solar cells
Applications

- display technology
- detector technology
- solar cells
Funding: Army Research Office

Acknowledgments:
Prof. Li Zhao (Fudan University)
Prof. Mike Aziz (Harvard University)

For a copy of this talk and additional information, see:
http://mazur-www.harvard.edu