

# Reversible Optical Recording on Epitaxial Indium Selenide Phase-Change Media

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*Hewlett-Packard*

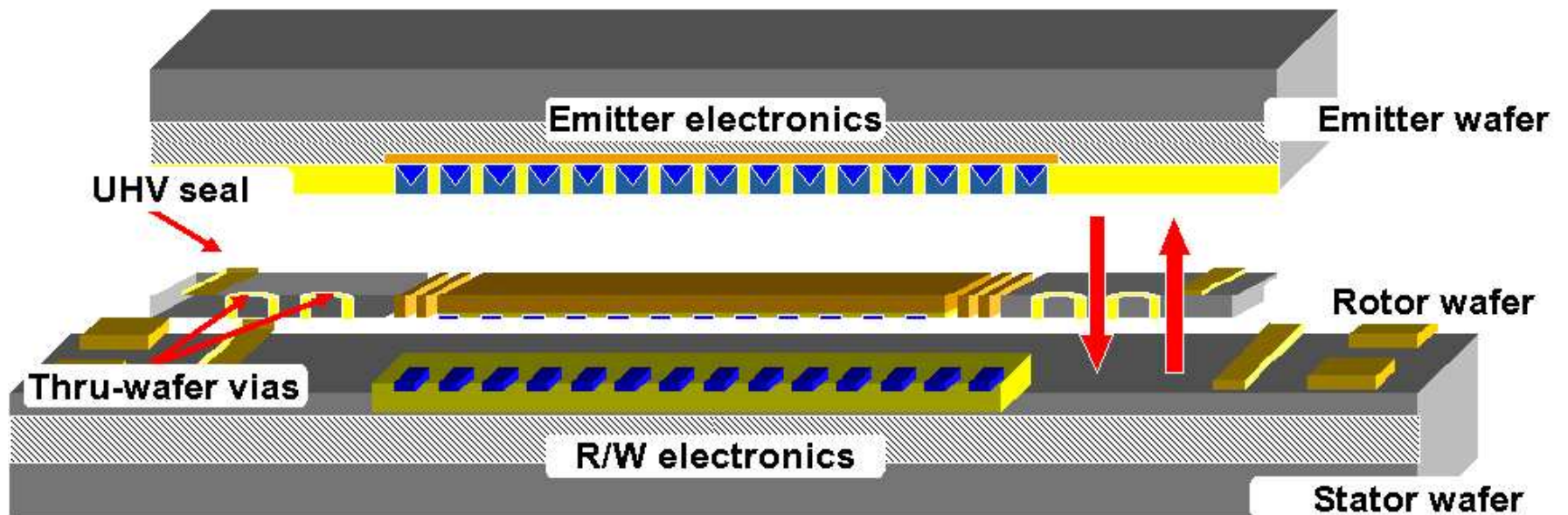
J.B. Jasinski and Z. Liliental-Weber  
*Lawrence Berkeley National Lab*



i n v e n t

# Electron-Beam Recording on Phase-Change Media

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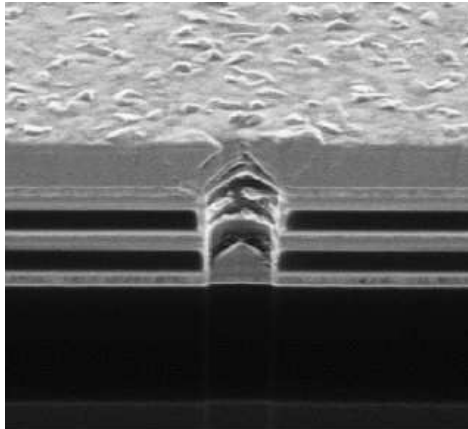


Features:

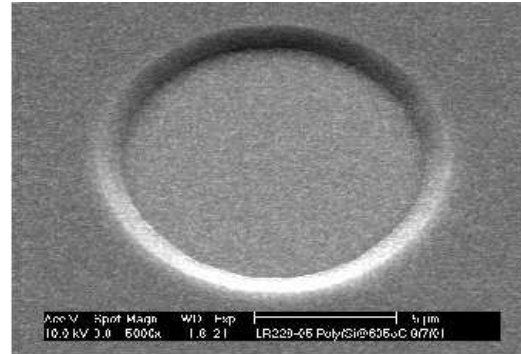
- Unpatterned media scanned in two dimensions;
- Reading and writing via electron-beam field emitters in vacuum;
- Phase-change media for data storage.

# Electron-Beam Emitters for Read/Write

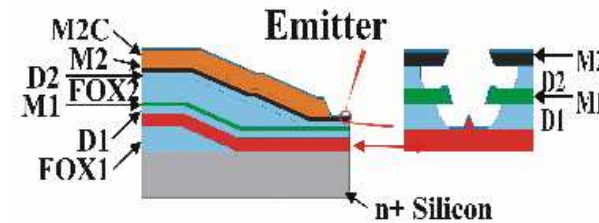
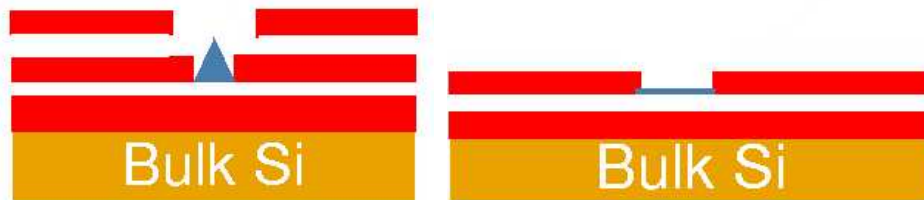
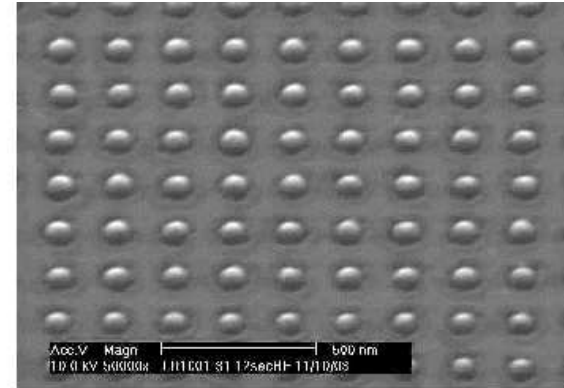
Spindt metal tips



Nodular MIS emitters



NanoTEL emitters

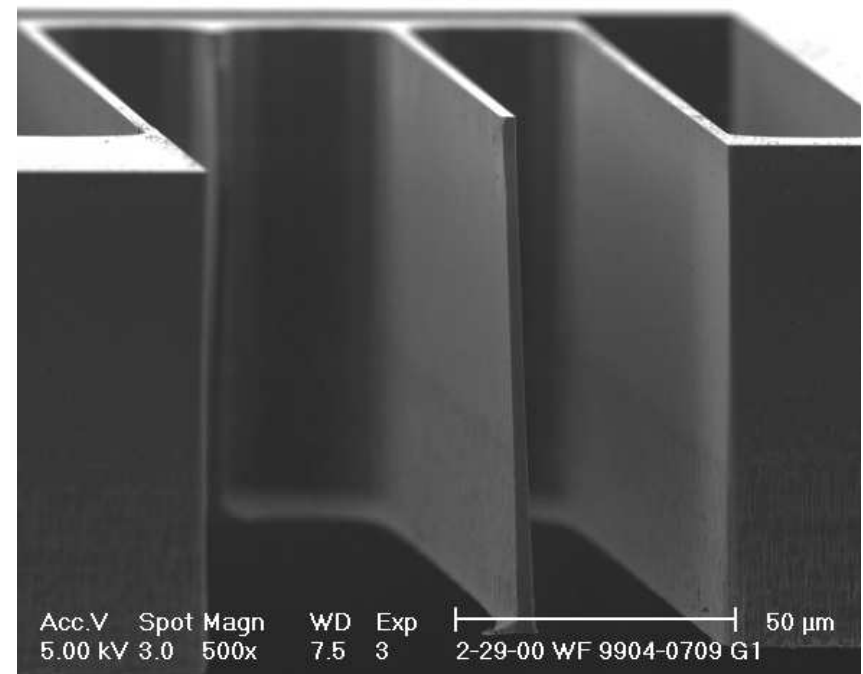
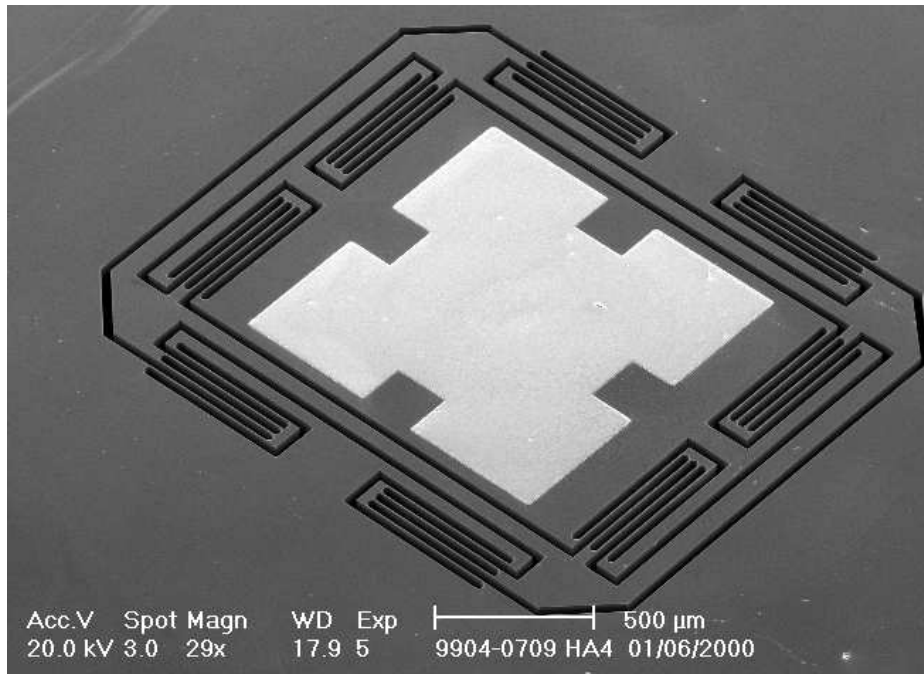


Considered 3 different kinds of emitters:

- Traditional Spindt evaporated metal emitters;
- Flat MIS emitters whose current originates from tiny poly-Si nodules;
- E-beam lithographic version of the nodule-enhanced flat emitters.

# MEMS X-Y Micromover for Media Scanning

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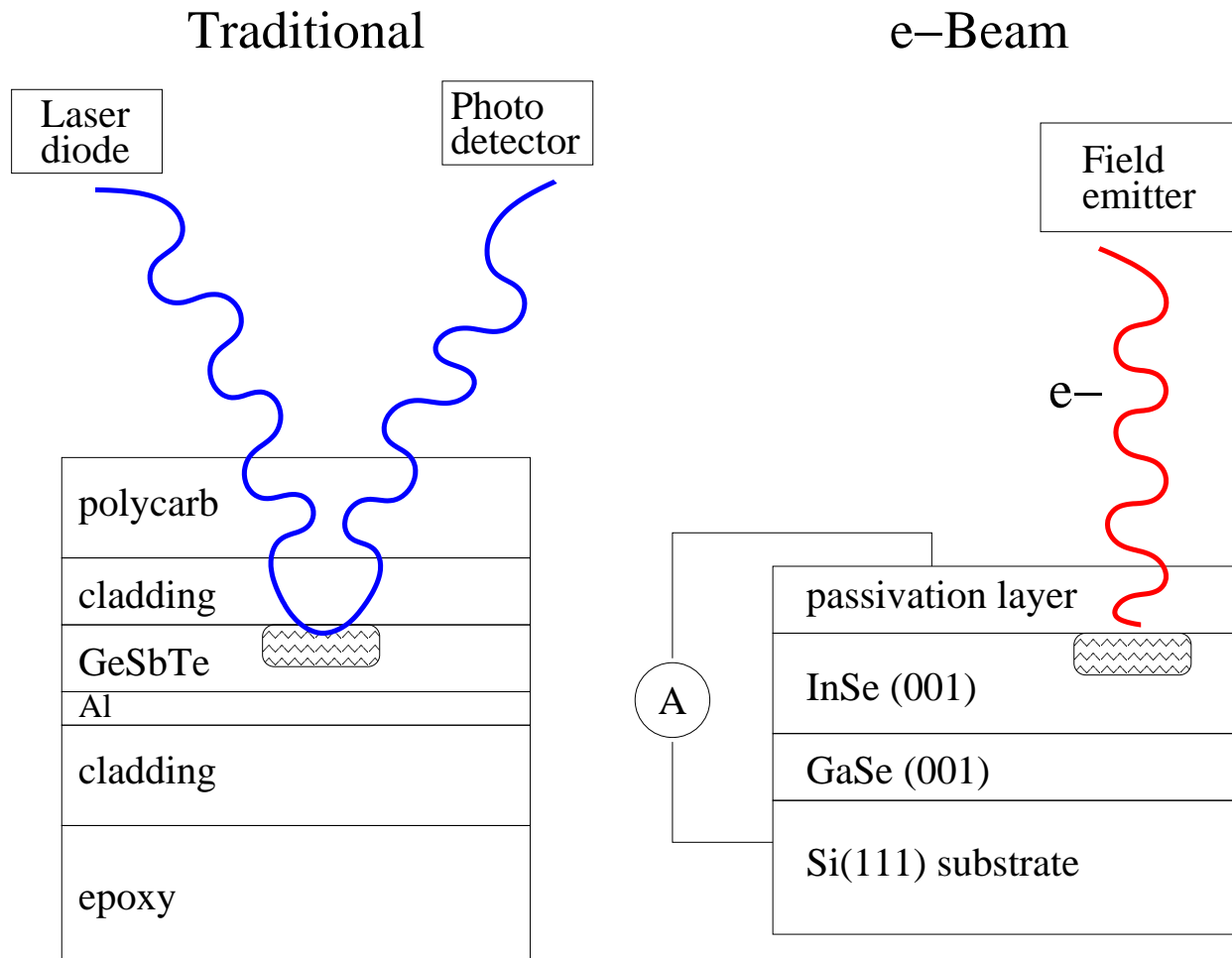


## Features:

- Deep Si etching allows 40:1 aspect-ratio springs;
- >600:1 out-of-plane:in-plane stiffness ratio;
- >50% areal efficiency;
- CMOS compatible process for integration of control electronics.

# Optical vs. Electron-Beam Recording

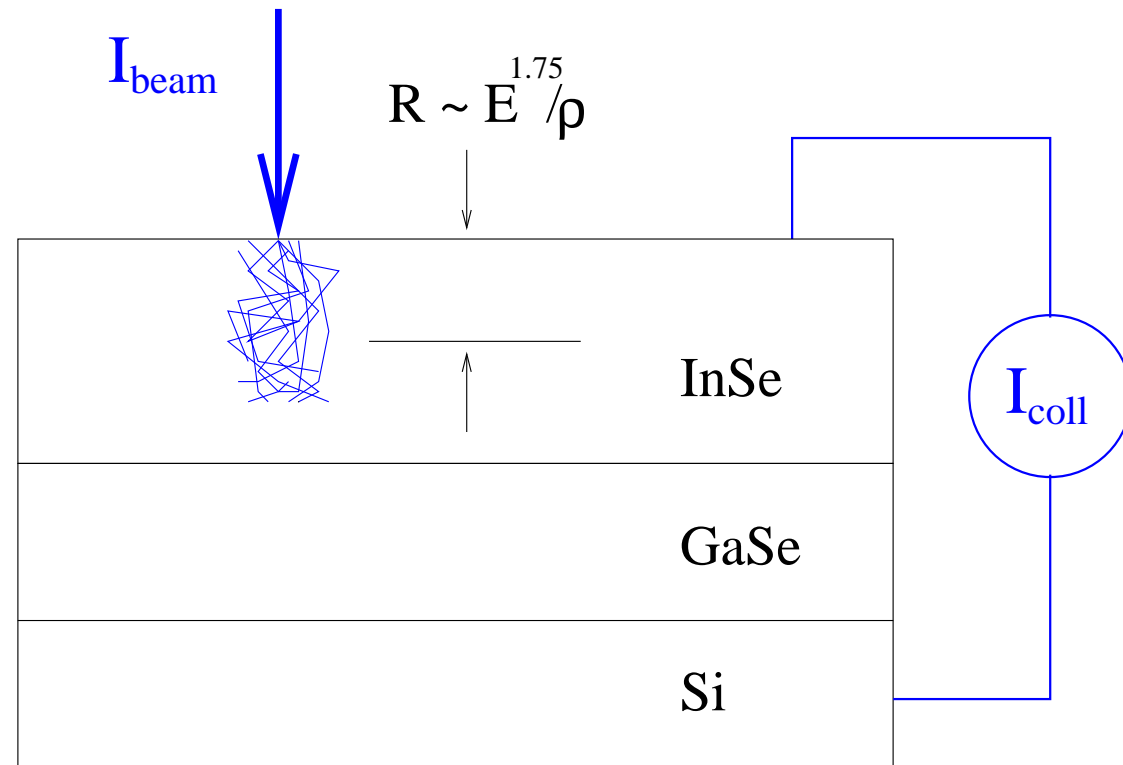
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The medium must be a phase-change material with good electrical properties!

# Electron-Beam Induced Current with keV Electrons Gives Gain

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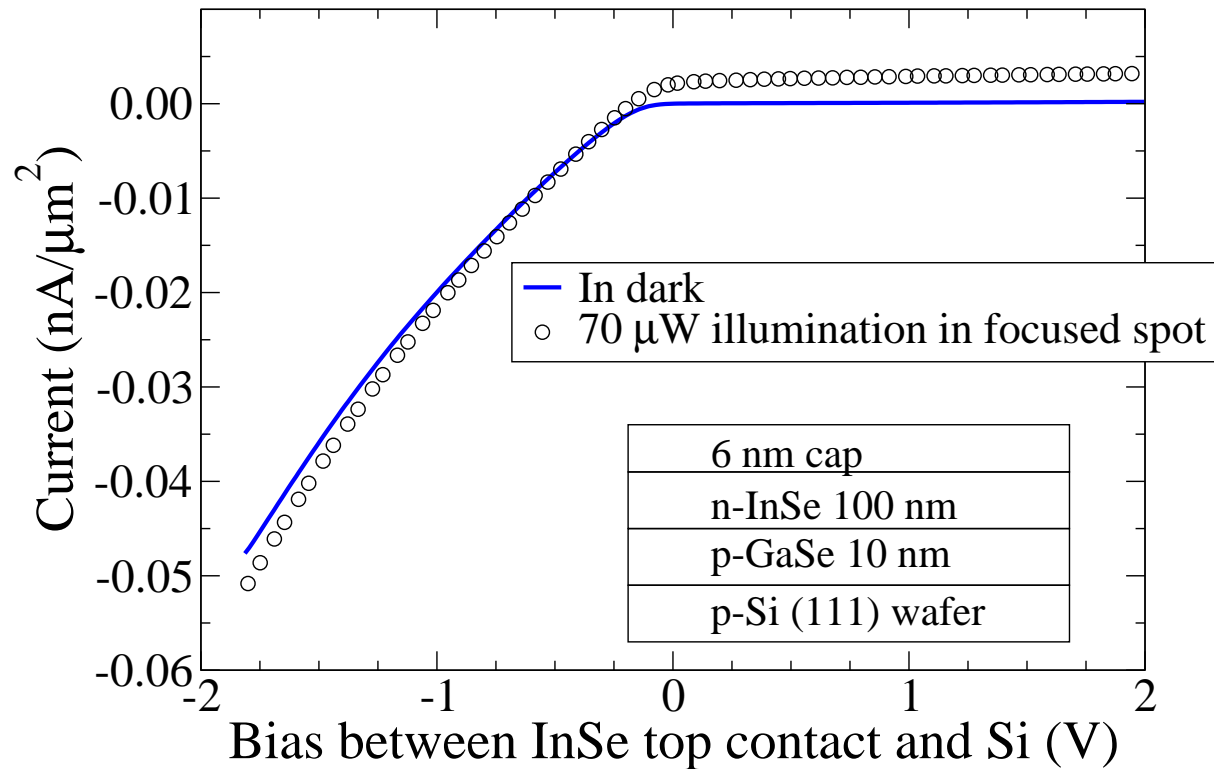


$$I_{\text{coll}} \approx (\text{collection efficiency}) * (E_{\text{beam}}/3 * E_{\text{bandgap}}) * I_{\text{beam}}$$

Gain  $\equiv I_{\text{coll}}/I_{\text{beam}}$ , as high as 65 at 2 keV.

# Decent Electrical Properties of InSe/GaSe Heterojunction Diodes

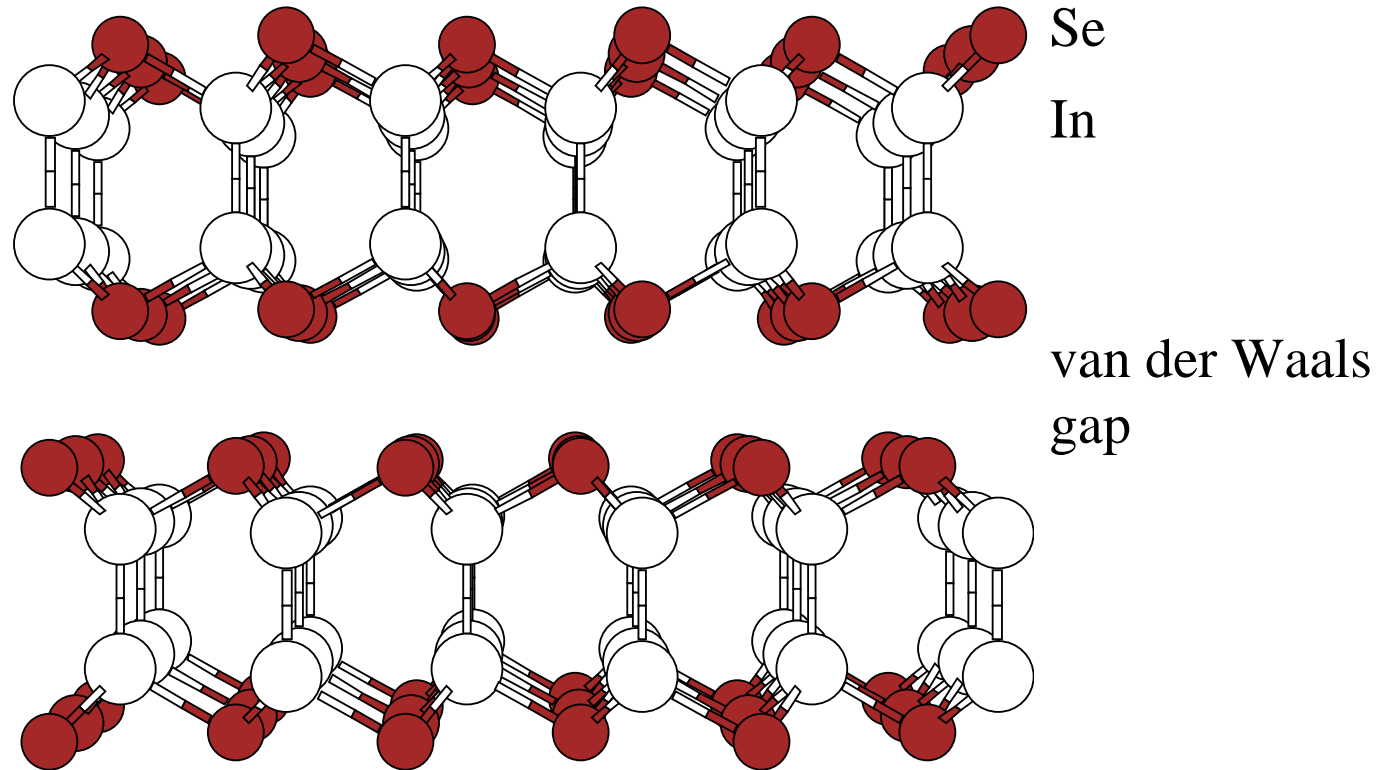
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GaSe is natively p-type, while InSe is natively n-type.  
Collection efficiencies 5-10%.

# Crystal Structure of III-VI InSe and GaSe

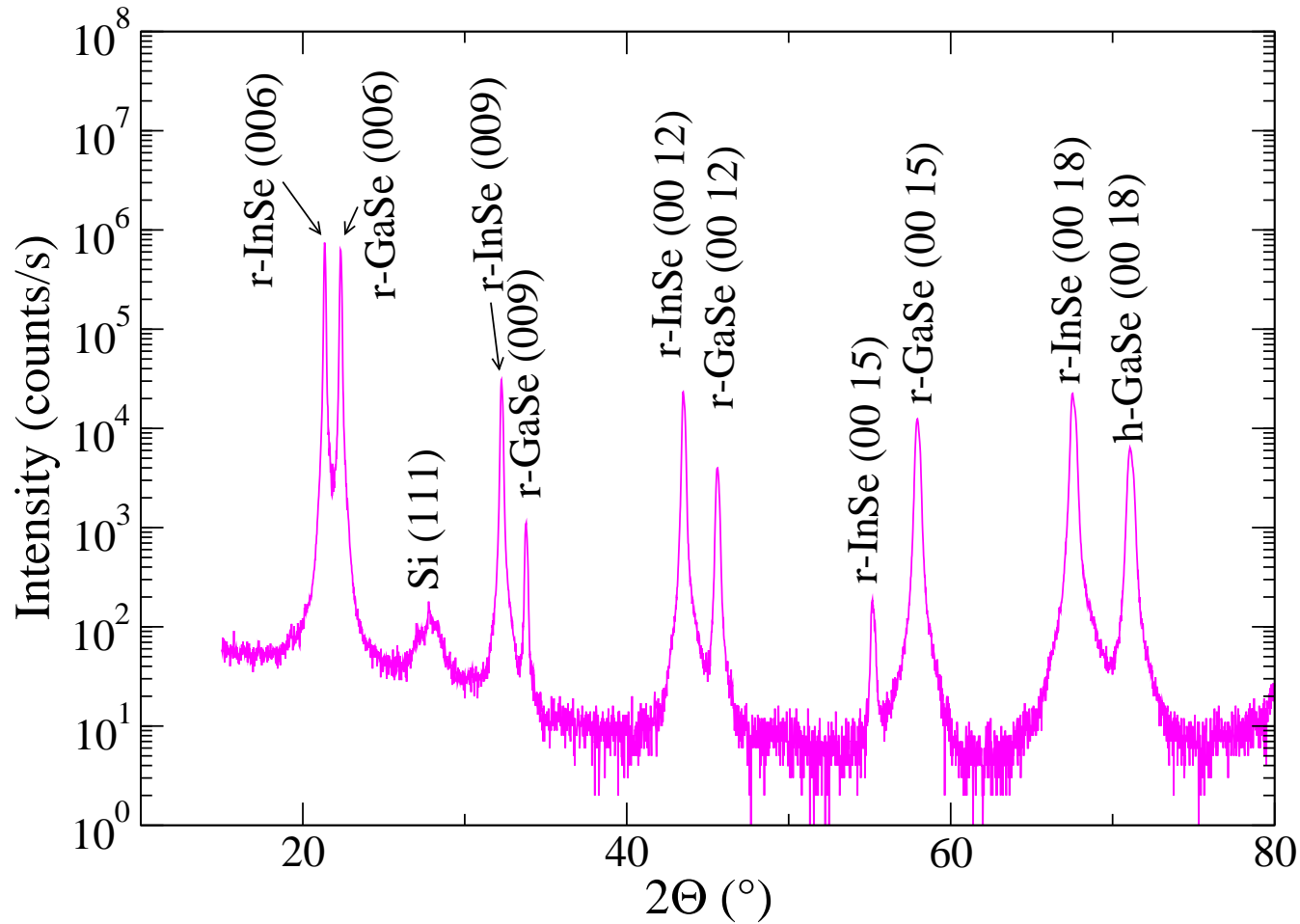
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- GaSe grows epitaxially on Si(111) [Palmer *et al.*, JJAP 1993]
- InSe grows epitaxially on GaSe [Nakayama *et al.*, Surf. Sci. 1991]
- Substantial electrical and thermal anisotropy in both materials.



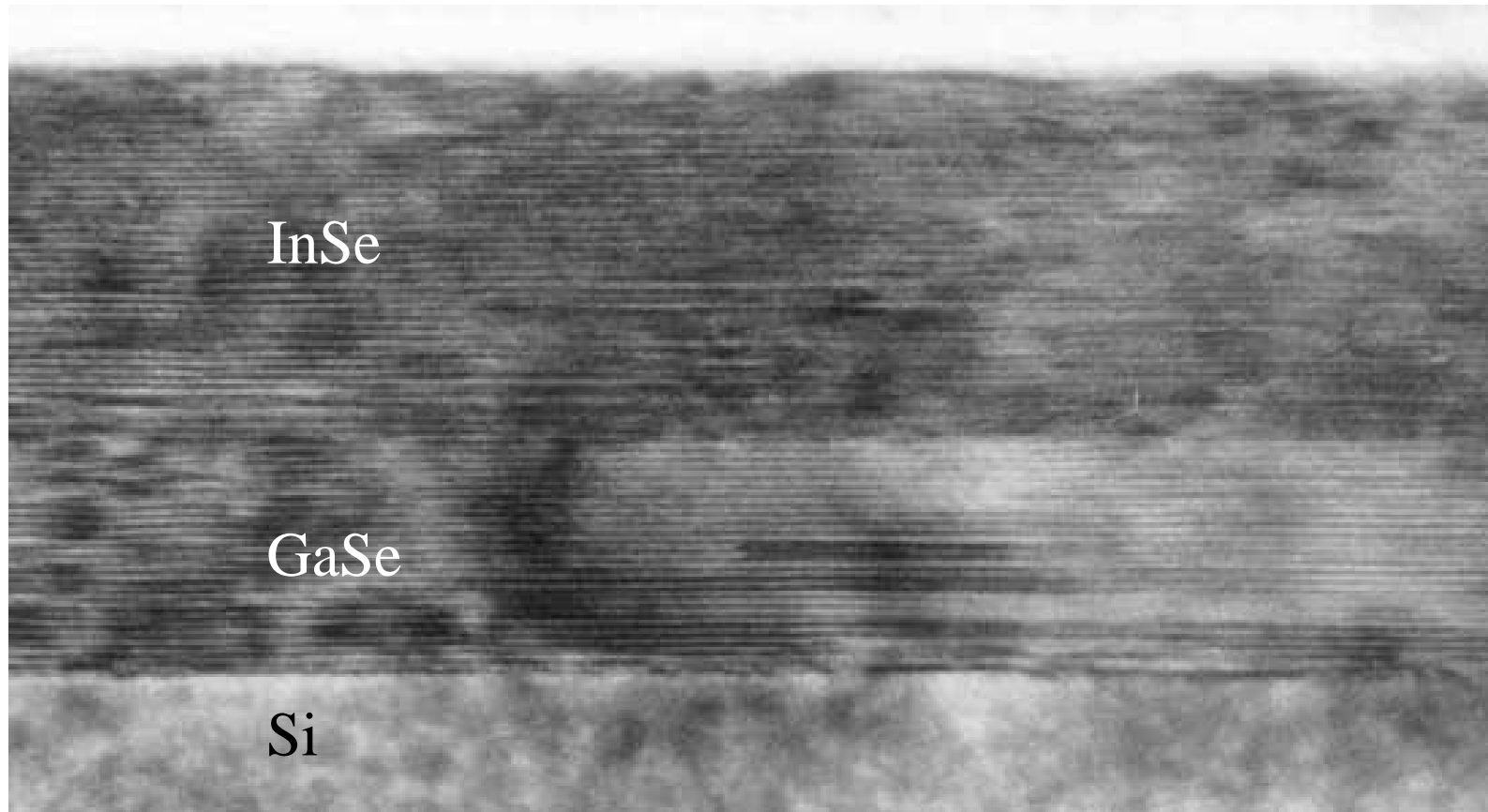
# Good Quality Epitaxial InSe/GaSe/Si(111) Films



Phase-change materials with decent semiconducting properties that grow well on Si!

# Good Quality Epitaxial InSe/GaSe/Si(111) Films

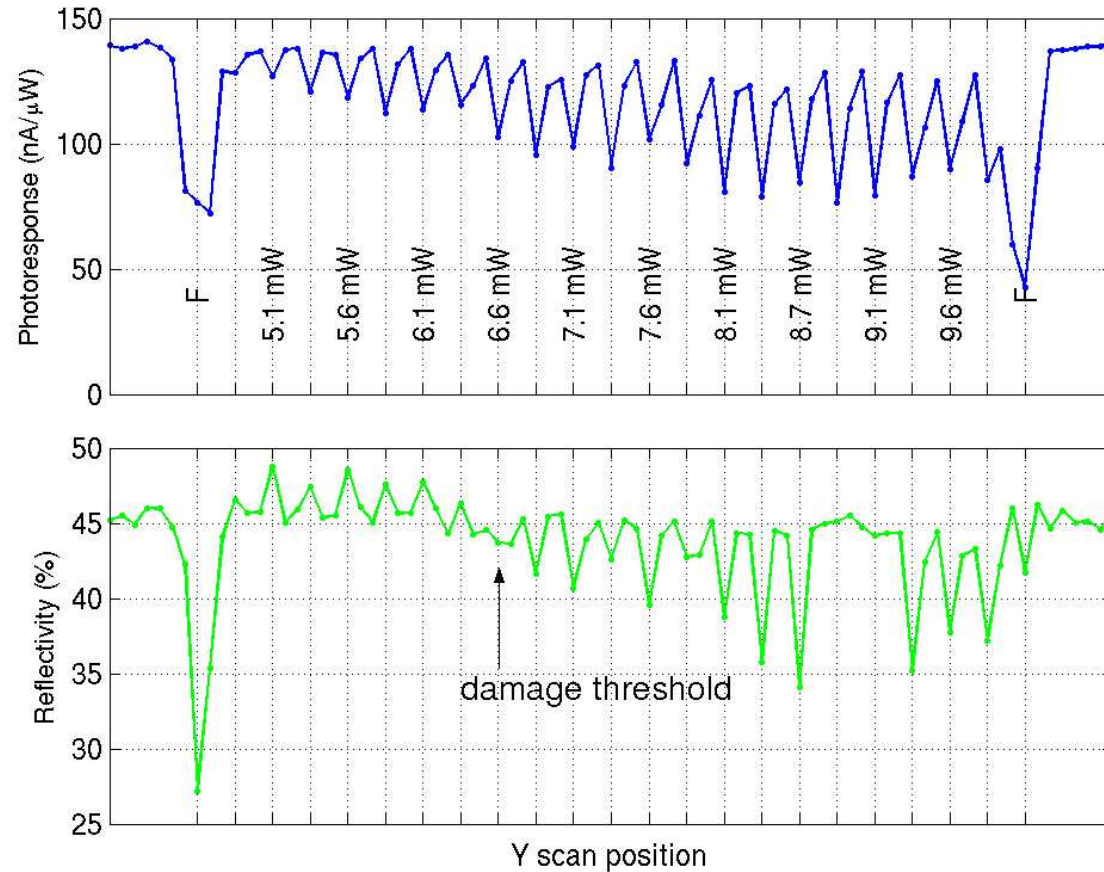
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Growth is subject to twins, stacking faults and threading dislocations as in familiar epitaxial systems.

See J.B. Jasinski *et al.*, MRS 2003 Symposium GG proceedings.

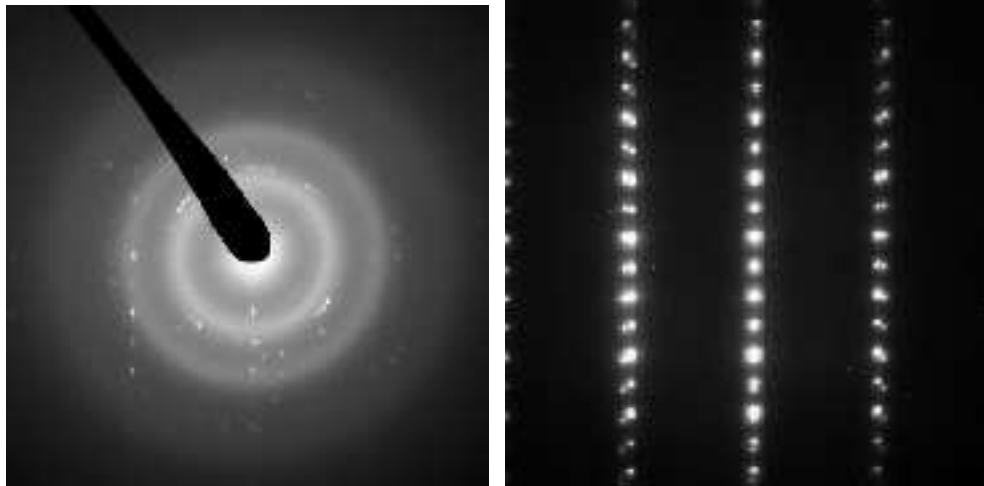
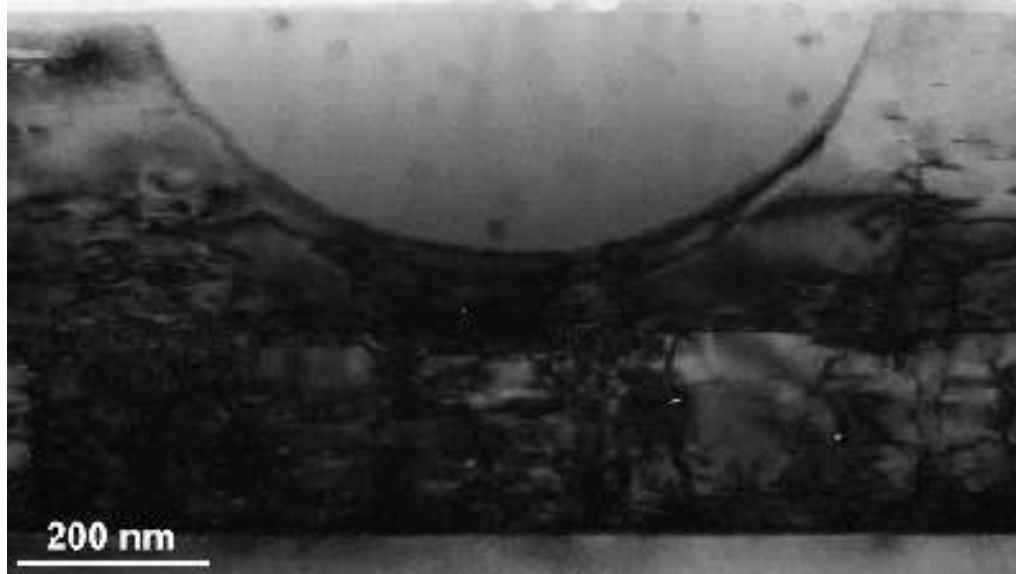
# Making Amorphous Laser Marks



Diffraction-limited, 30 nS 488 nm laser marks.  
Reflectivity changes sign at damage threshold.

# Amorphous Laser Marks

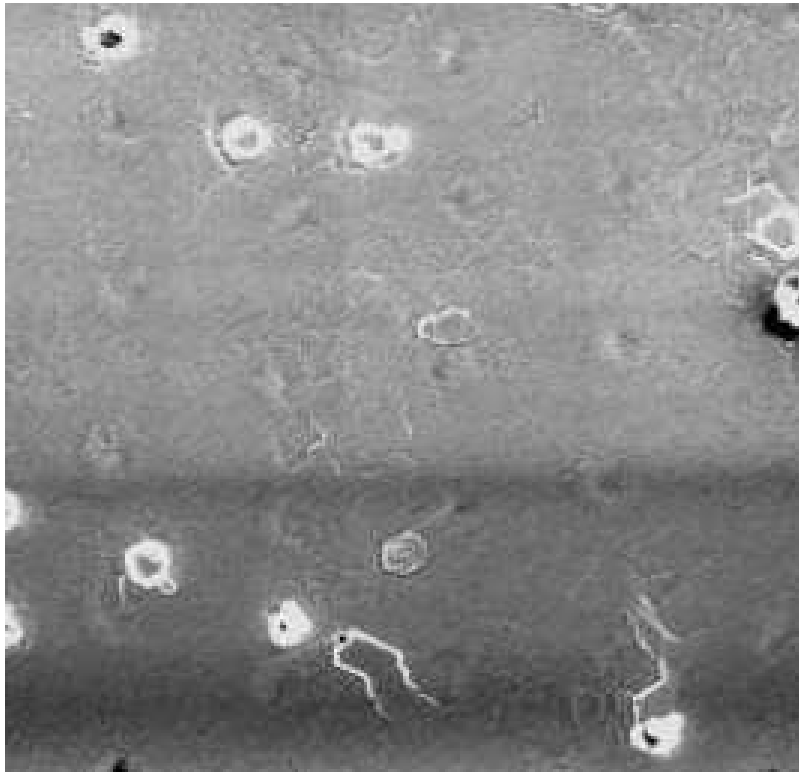
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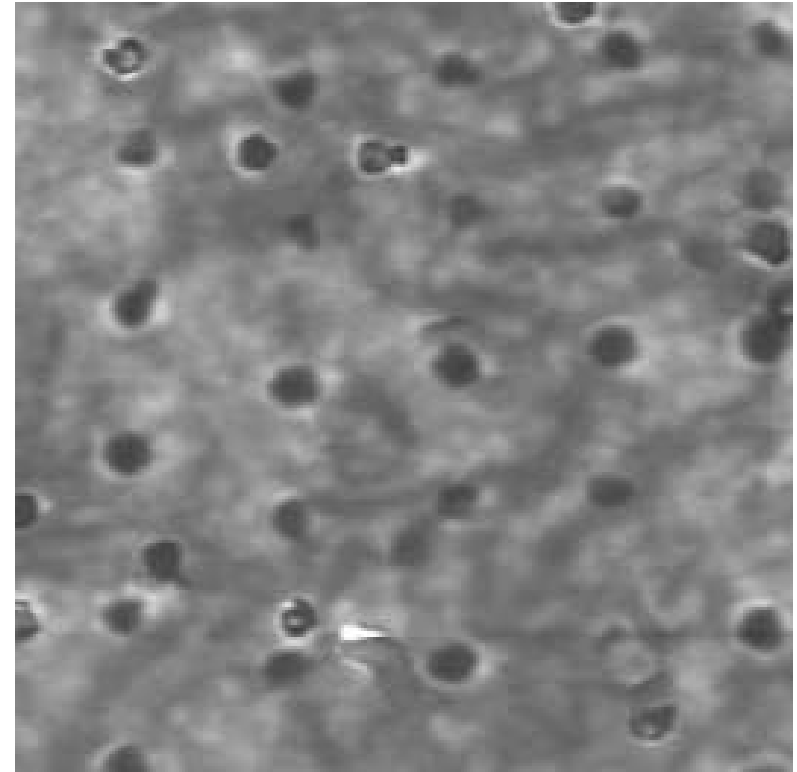
Laser used to simulate e-beam recording.

# Electronic Contrast Observed without Surface Damage

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SEM Image



EBIC image

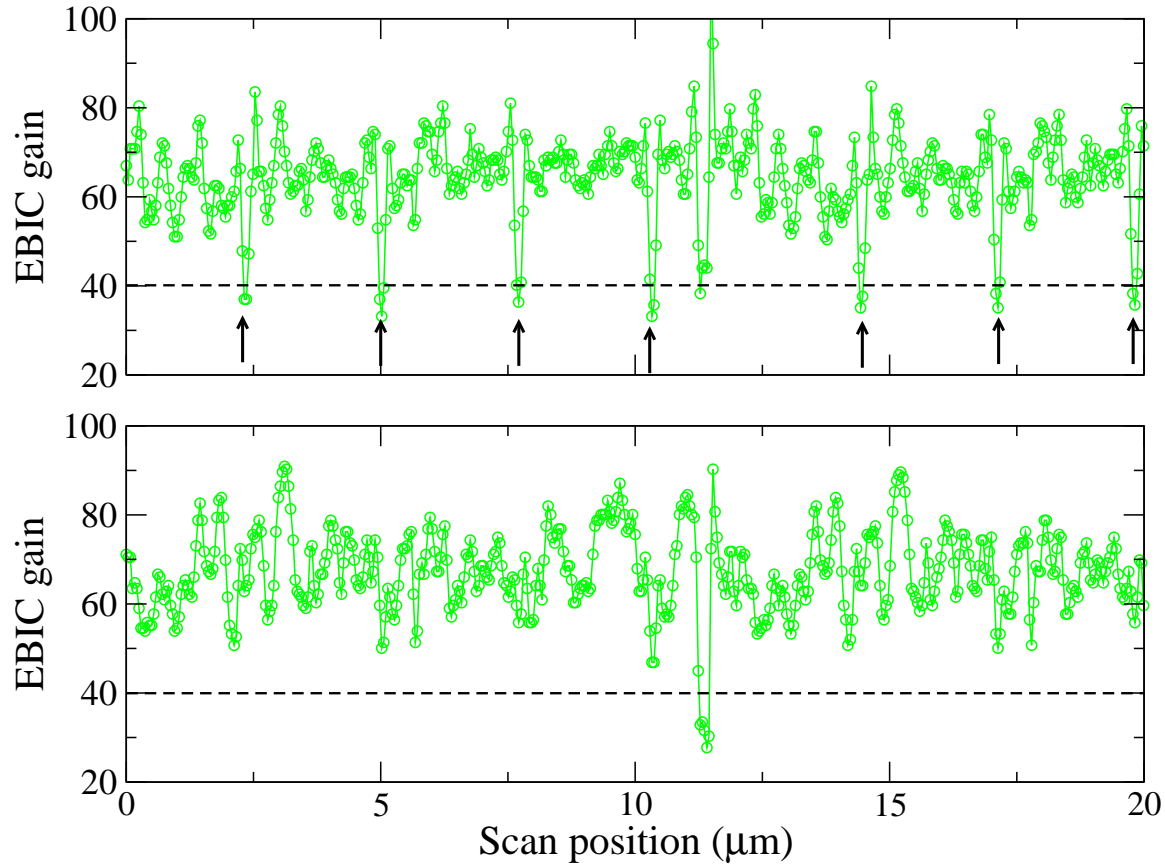
Marks are barely visible in SEM image. Spacing =  $0.9 \mu\text{m}$ .

Inclusions cause large “media noise.”

Pulsewidth < thermal equilibration time gives small mark diameter  $\approx 200 \text{ nm}$ .

# Oven Erasure of Amorphous Bits

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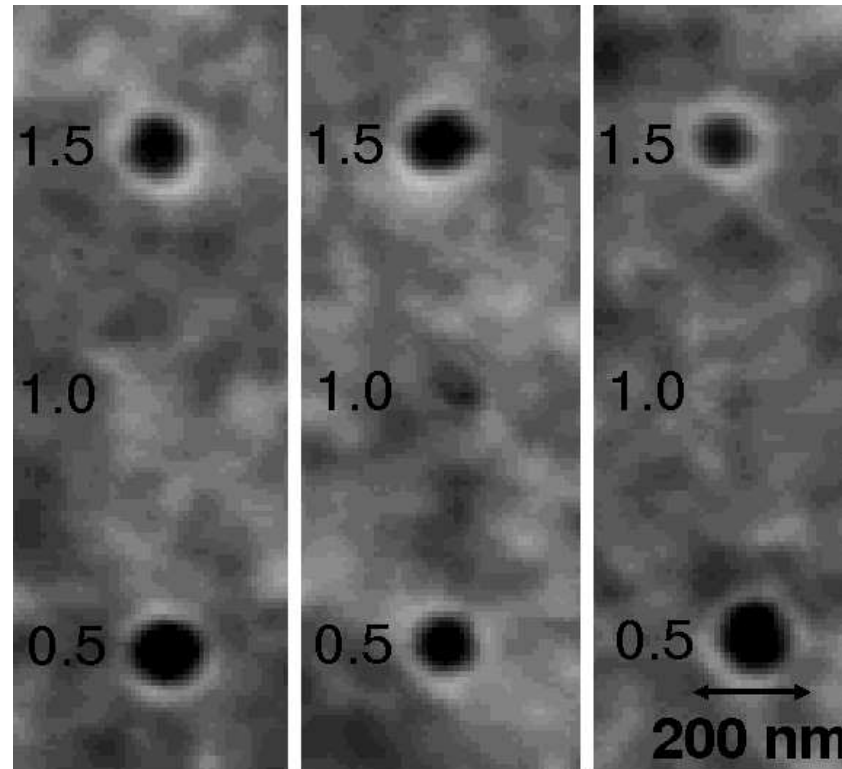


Annealed at 300 °C for 5 minutes.

All amorphous bits have a gain  $< 40$  before annealing and  $\geq 50$  afterwards.

# Erasure without Surface Damage

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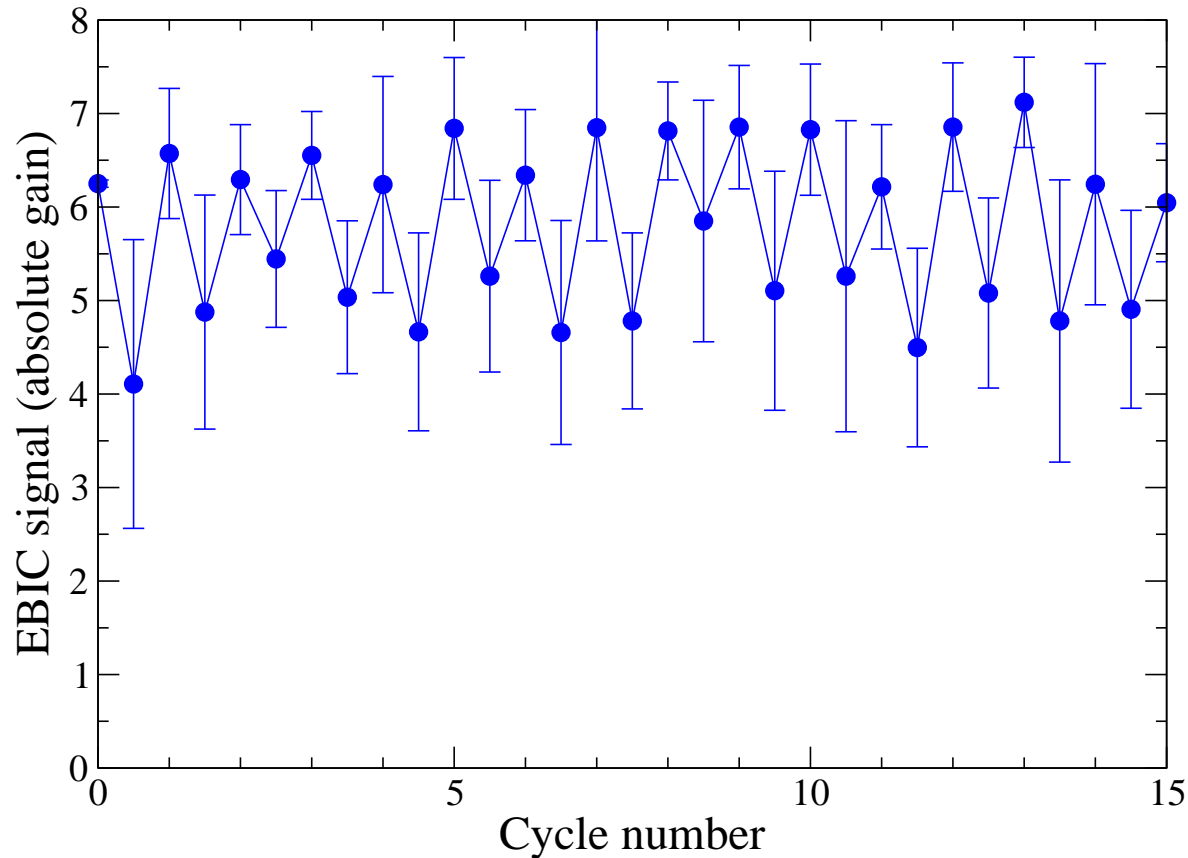
0.5 = Write pulse only; 1.0 = Write/Erase; 1.5 = WEW ...

$W = 4.7 \text{ mW}, 30 \text{ nS}; E = 1.8 \text{ mW}, 1 \text{ mS}.$

Up to 100 cycles with only minor degradation.

# 15 Cycles without Degradation Achieved

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Points indicate values obtained by averaging across rows of a matrix.

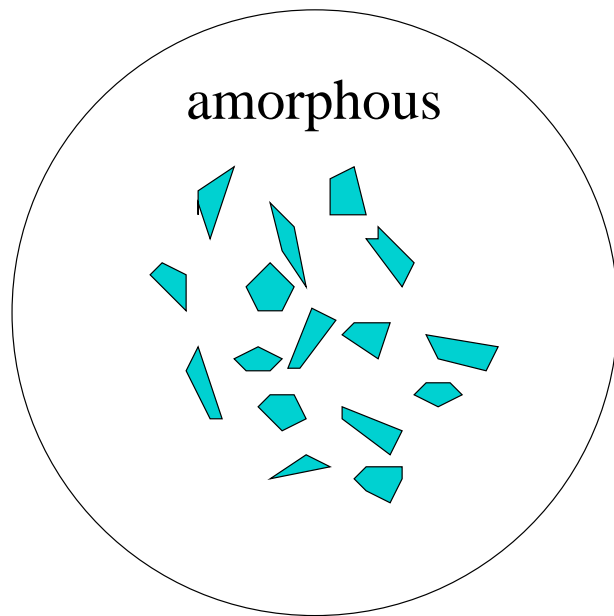
Optimize contrast via improved film growth, film thickness, cap layer parameters, beam energy and device bias.



# Scaling of Erasure Time Depends on Recrystallization Mode

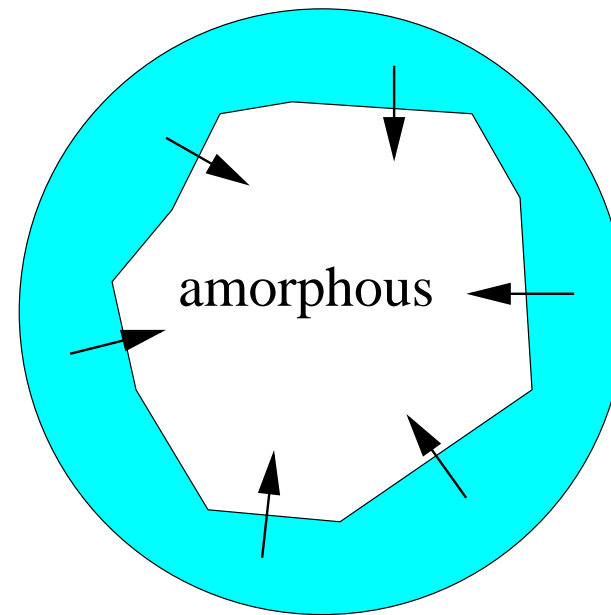
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Homogeneous nucleation  
plus growth



Like GeSbTe

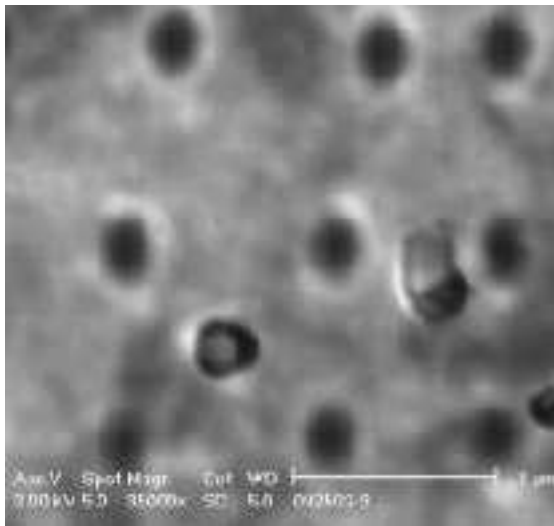
Regrowth from crystalline matrix  
without nucleation



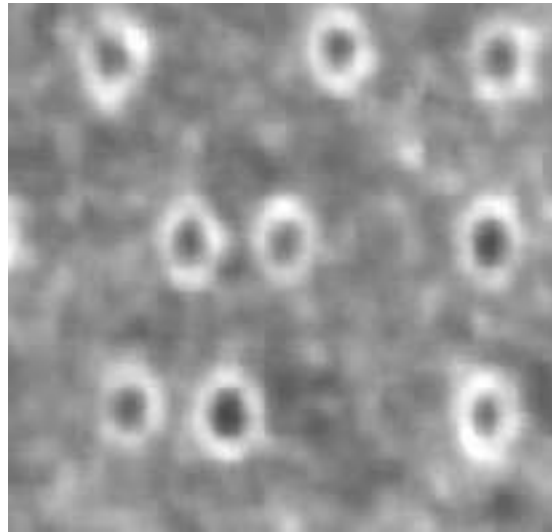
Like InAgSbTe

# Some Evidence for Regrowth from the Matrix

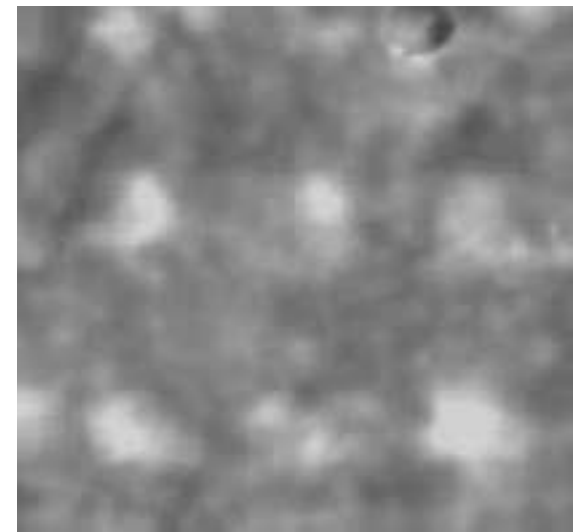
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Write pulse only



Write + 10  $\mu$ S erase



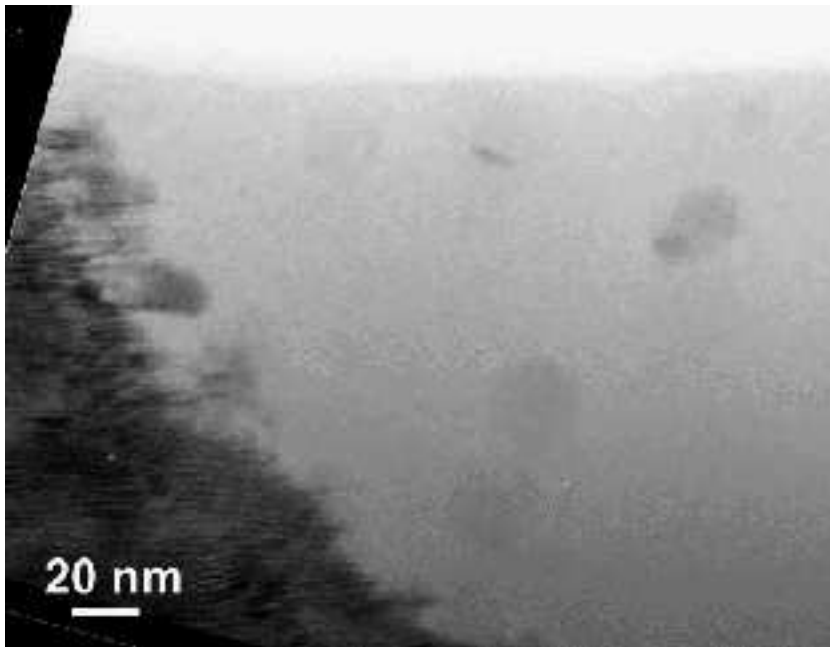
Write + 100  $\mu$ S erase

As erase pulse lengthens, bright ring grows inward.

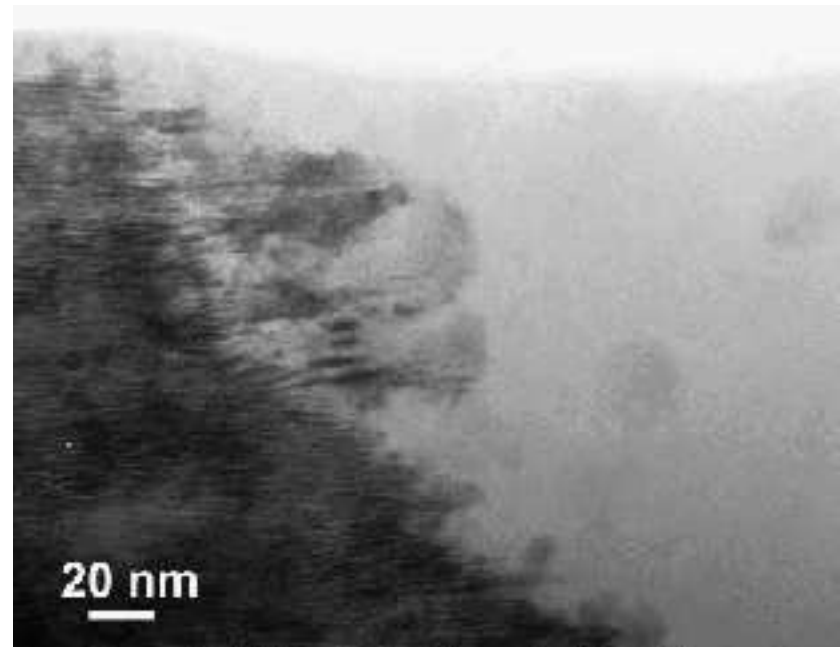
Final mark has larger signal than surrounding matrix.

# In Situ TEM Recrystallization Occurs from Mark Edge

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Write pulse only

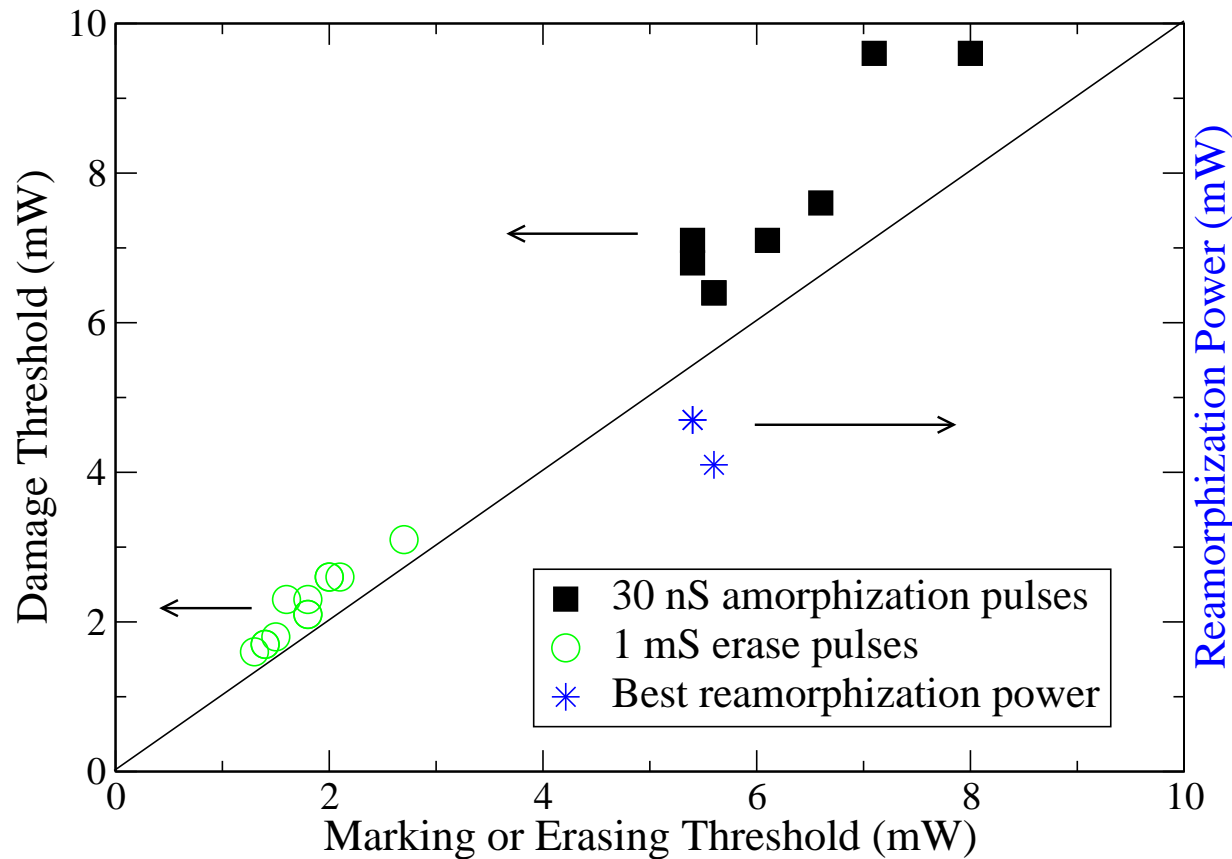


Write + 1 S irradiation

*In situ* TEM observation of electron-beam exposure suggest re-growth from the edge.

Growth-dominant behavior can occur under some circumstances.

# Margins for Write and Erase Processes are Small



Larger margins correspond to thicker cap layers.

Best cycling behavior has not been demonstrated on films with best gains.

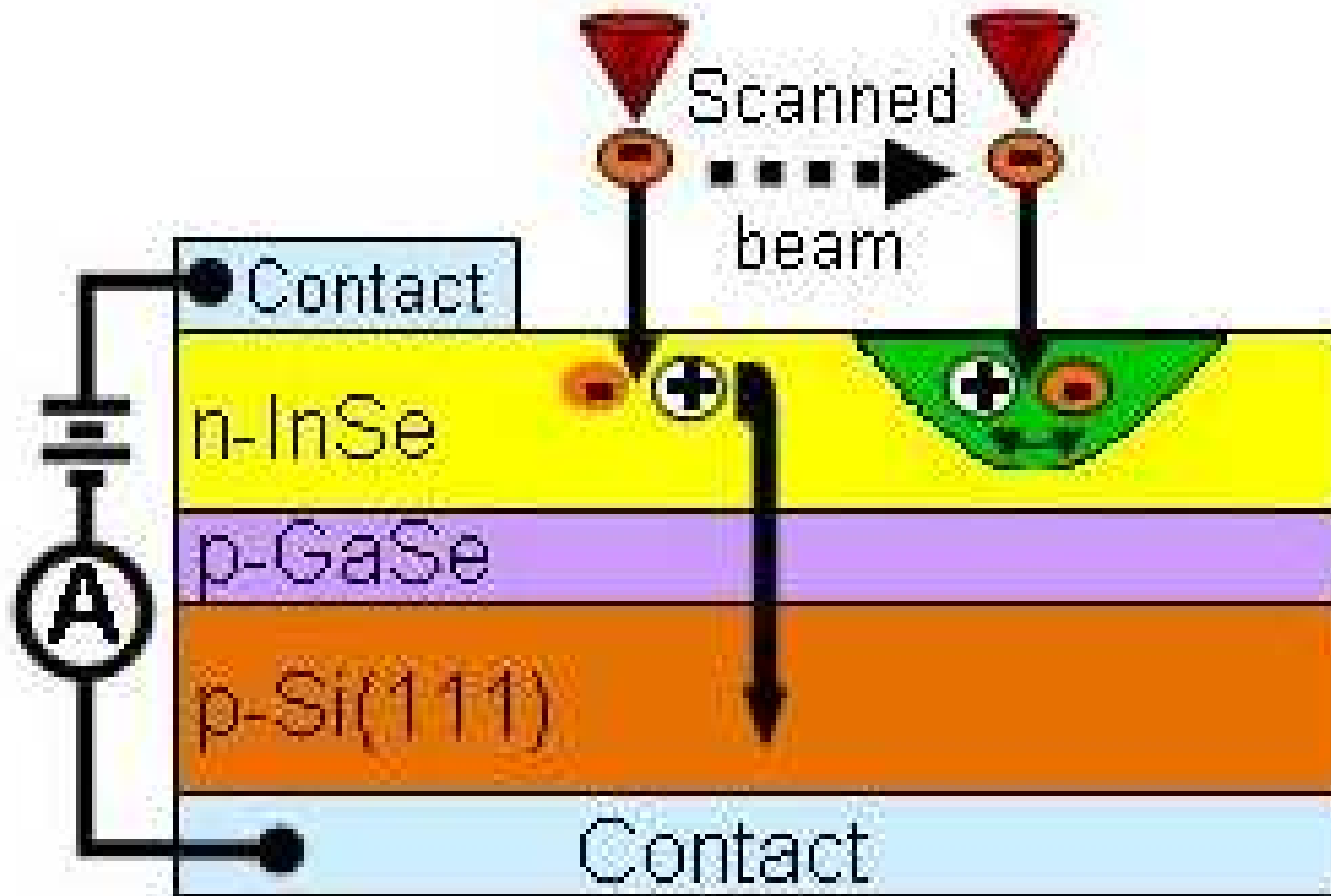
# Summary

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- High-quality phase-change media films have been grown on Si(111).
- The III-VI semiconductor phase-change media form diodes with reasonable collection efficiency.
- Erasable laser marks give a usable contrast in diode signal.
- Apparent growth-dominant behavior implies short erasure time for small-diameter marks.
- Up to 100 write-erase cycles have been achieved without significant degradation.
- Optimization of film growth, device design and read/write strategy has a long way to go.

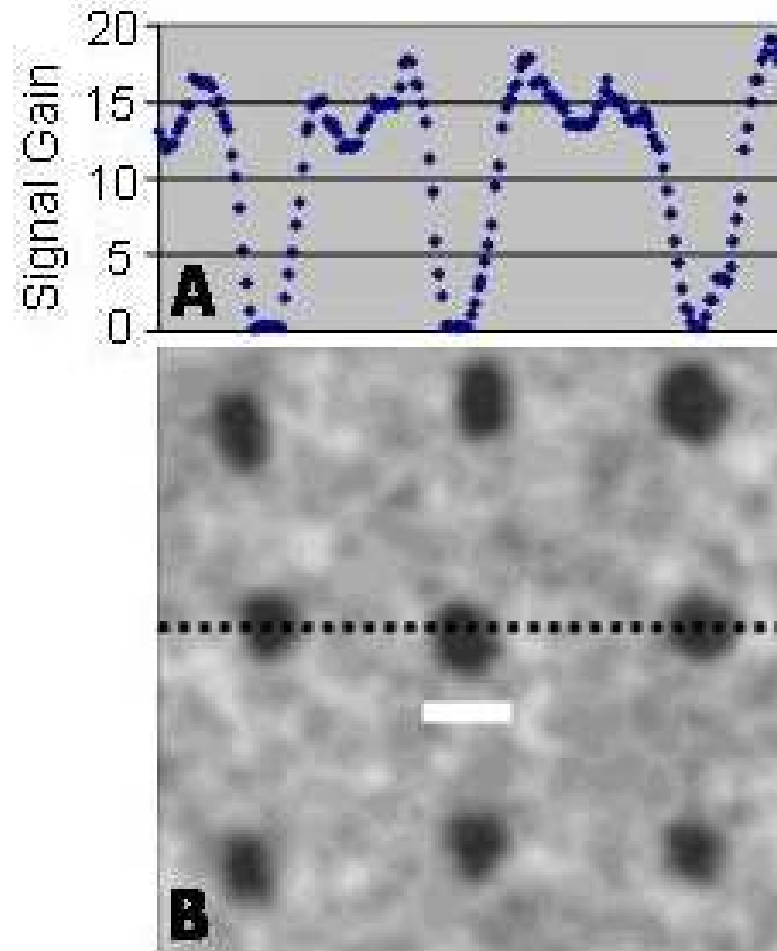
# Data Readback Concept

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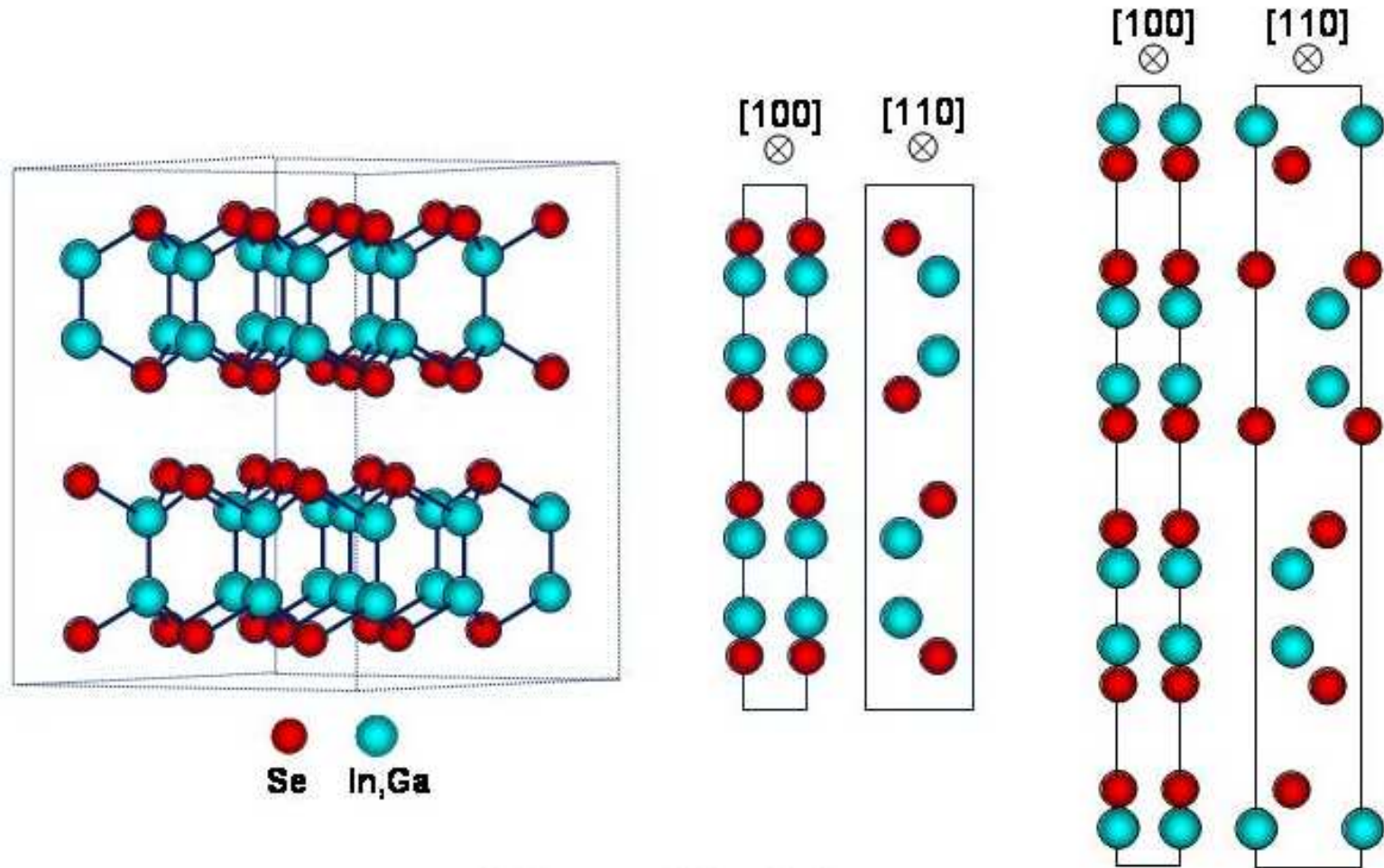


# Electron-Beam Readback of a Data Track

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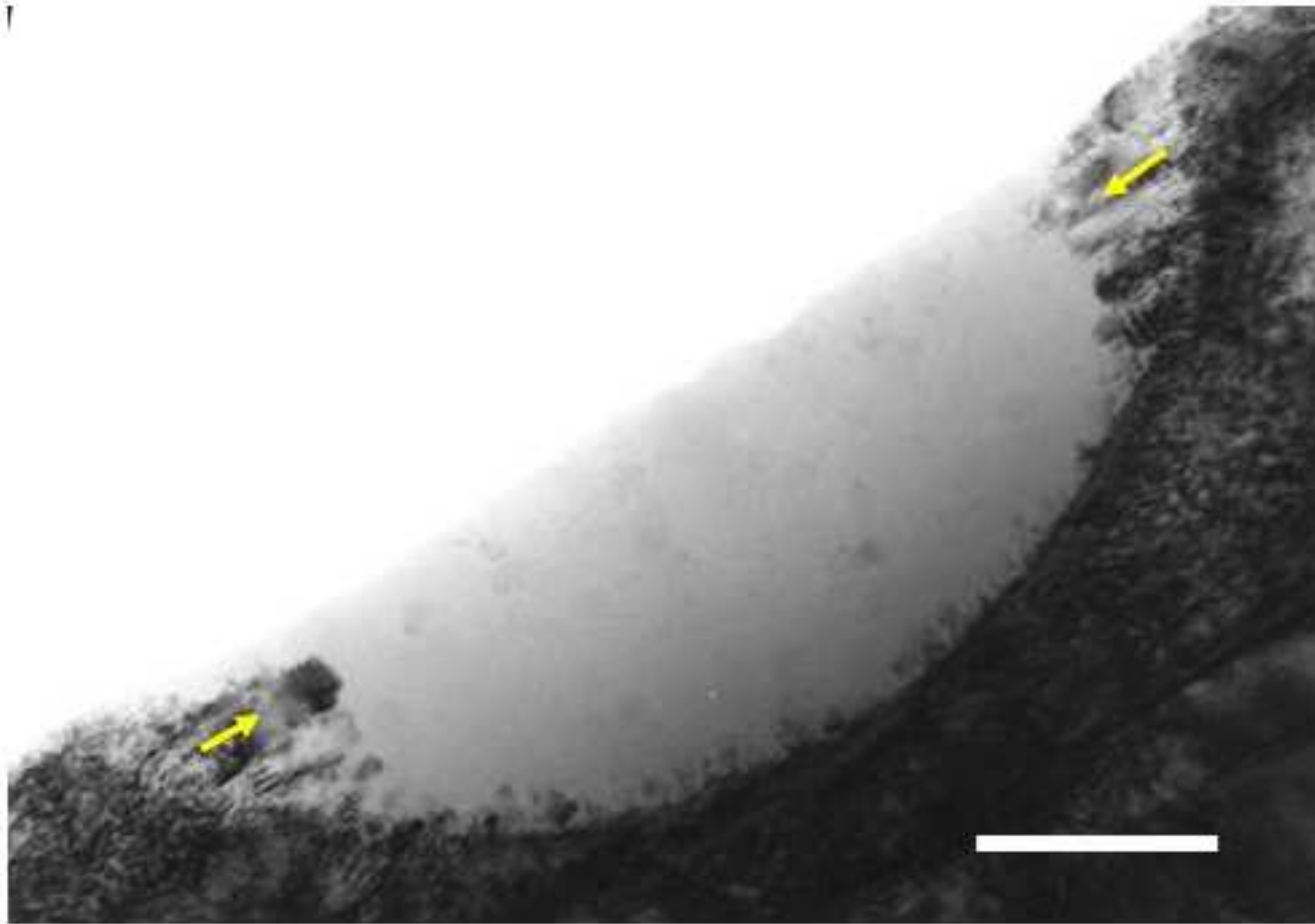
# InSe and GaSe Crystal Structure





# Larger View of E-beam Recrystallization at Edges

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Diameter of bit at surface is about 800 nm (much larger than erasable bits).