Reversible Optical Recording on Epitaxial Indium Selenide Phase-Change Media

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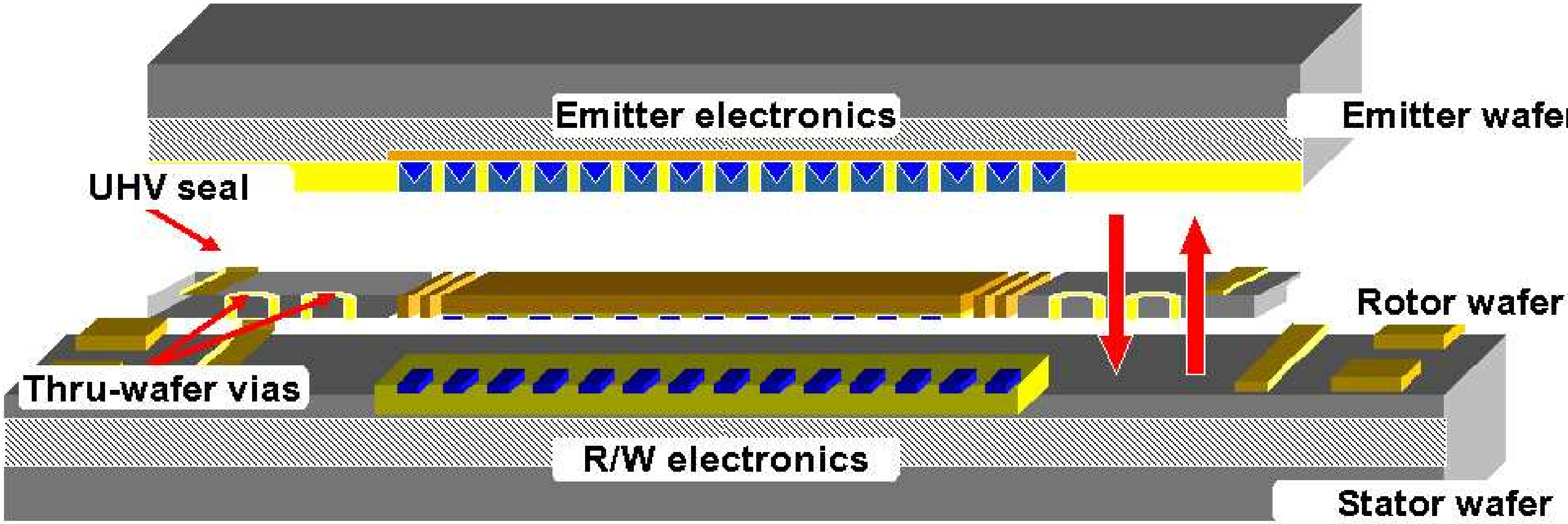
invent

Electron-Beam Recording on Phase-Change Media

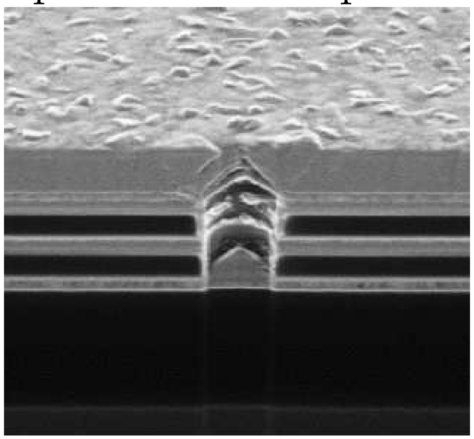


Features:

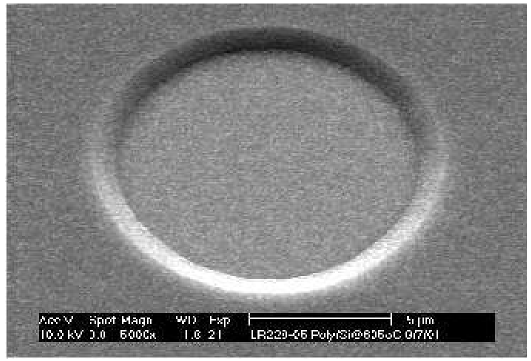
- Unpatterned media scanned in two dimensions;
- Reading and writing via electron-beam field emitters in vacuum;
- Phase-change media for data storage.

Electron-Beam Emitters for Read/Write

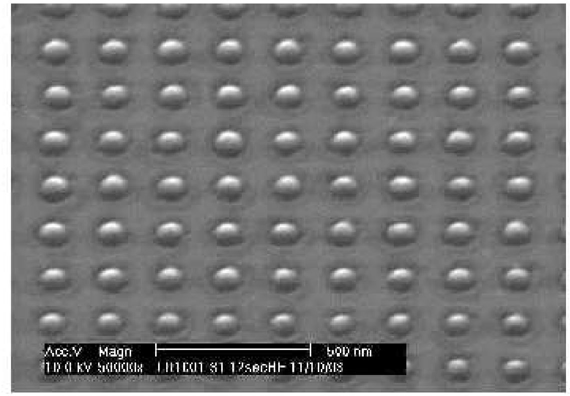
Spindt metal tips

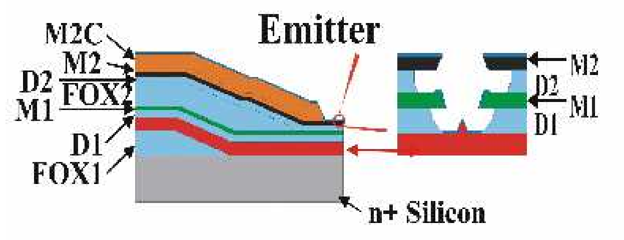


Nodular MIS emitters



NanoTEL emitters

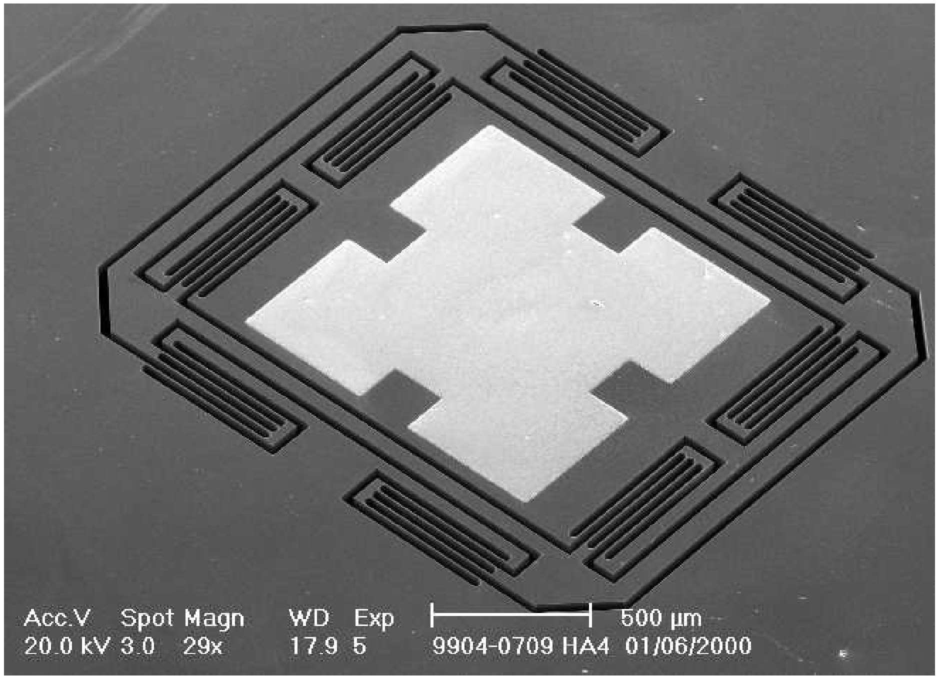


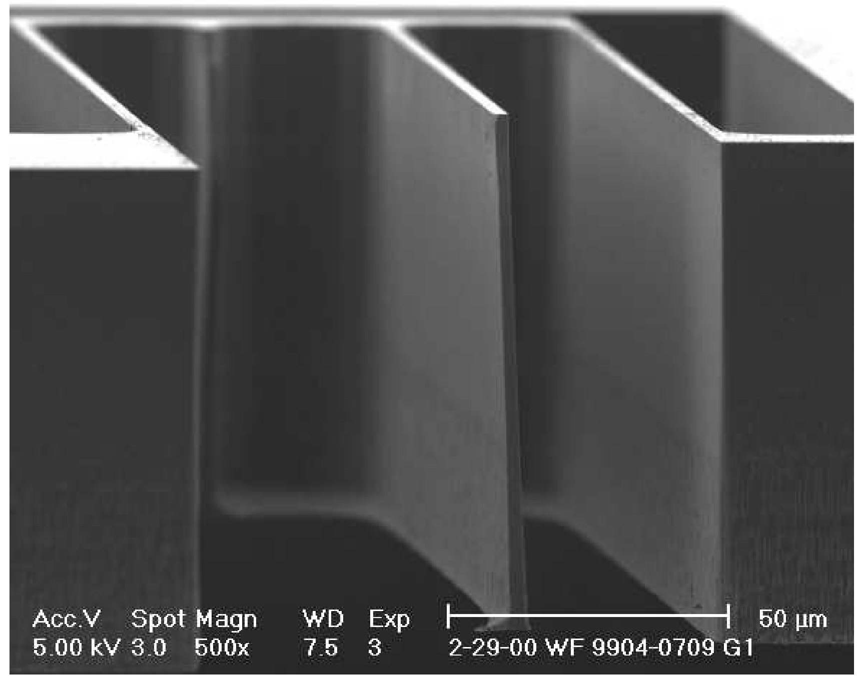


Considered 3 different kinds of emitters:

- 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

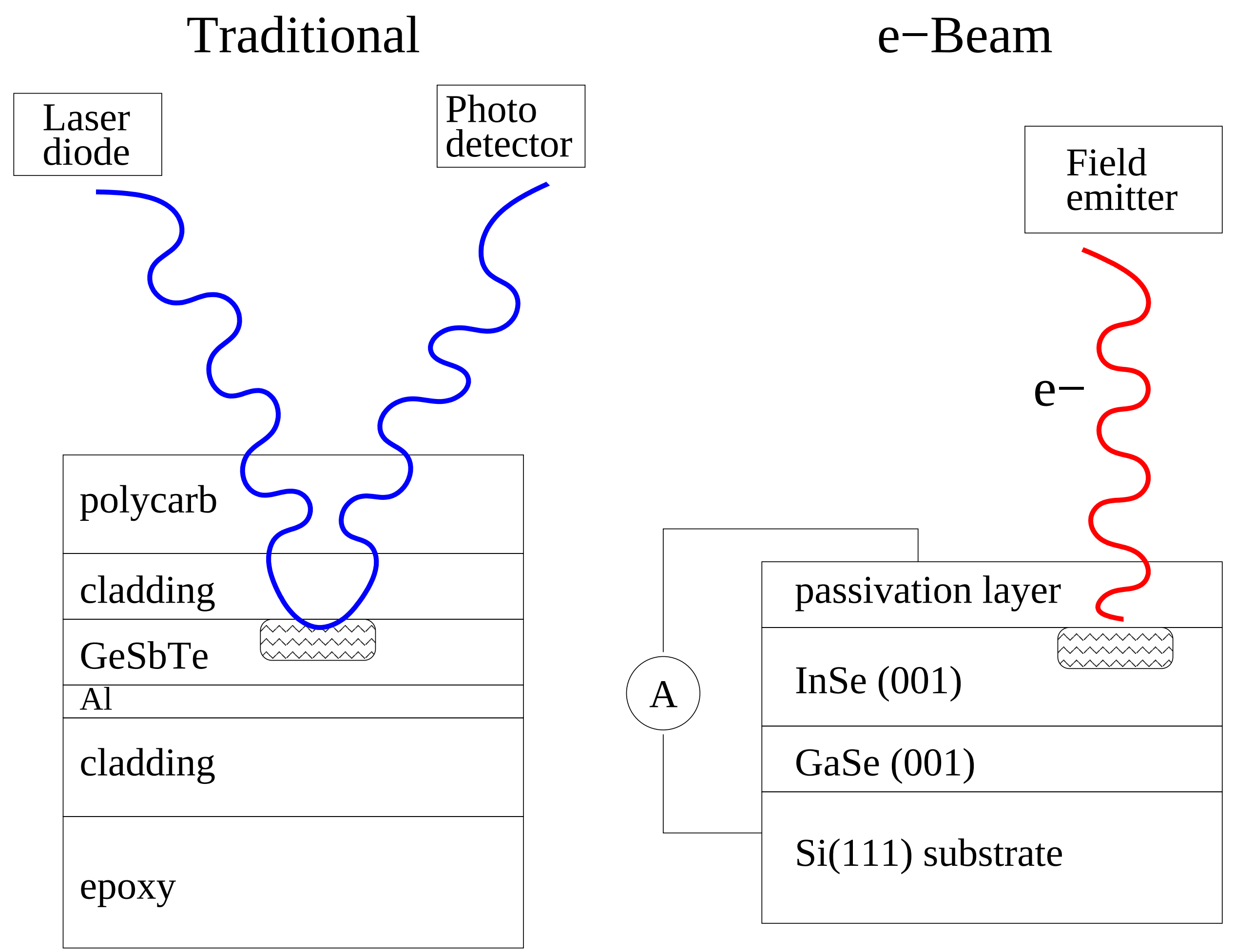




Features:

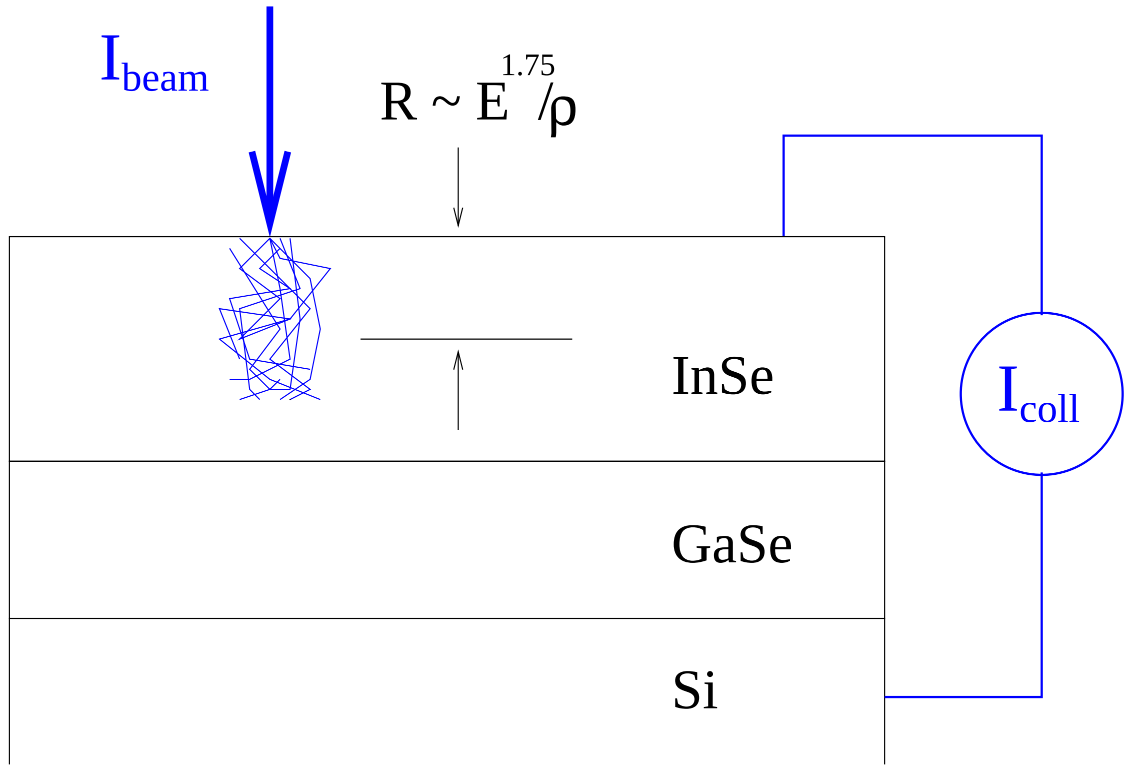
- Deep Si etching allows 40:1 aspect-ratio springs;
- >600:1 out-of-plane:in-plane stiffness ratio;
- >50% areal efficiency;
- CMOS compatible process for integration of control electronics.

Optical vs. Electron-Beam Recording



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

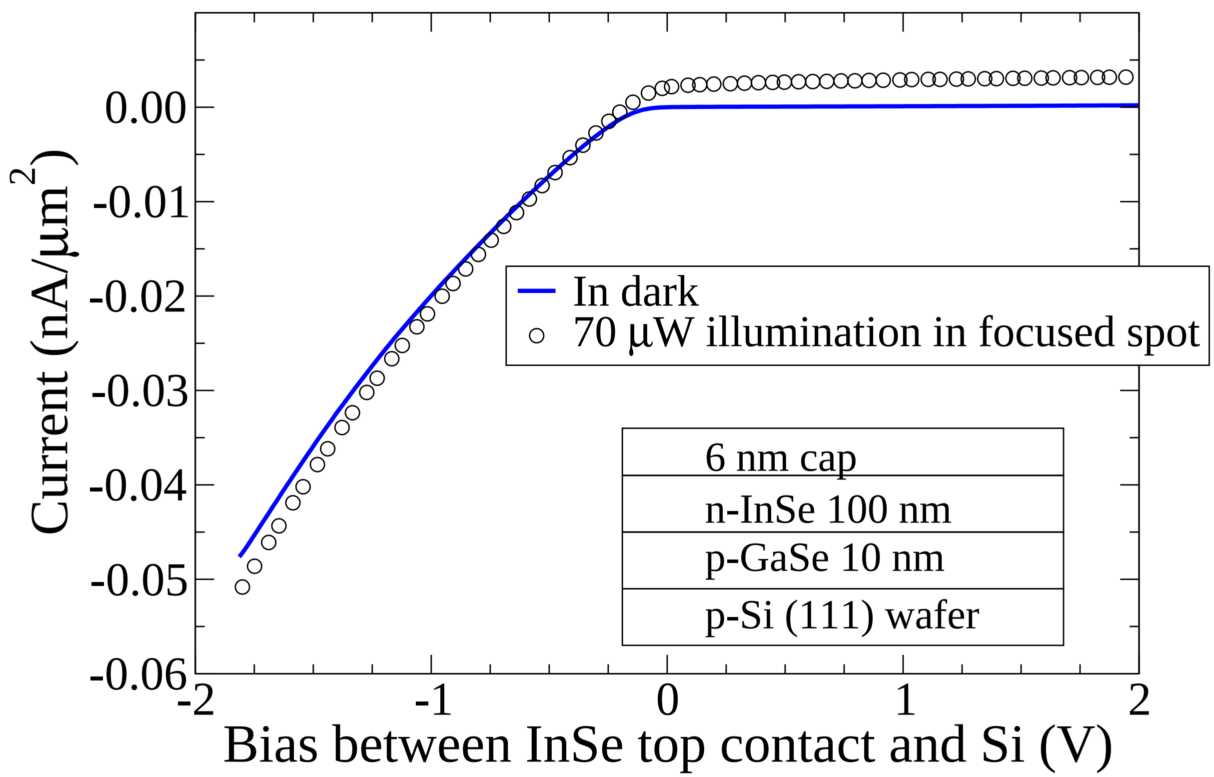
Electron-Beam Induced Current with keV Electrons Gives Gain



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

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

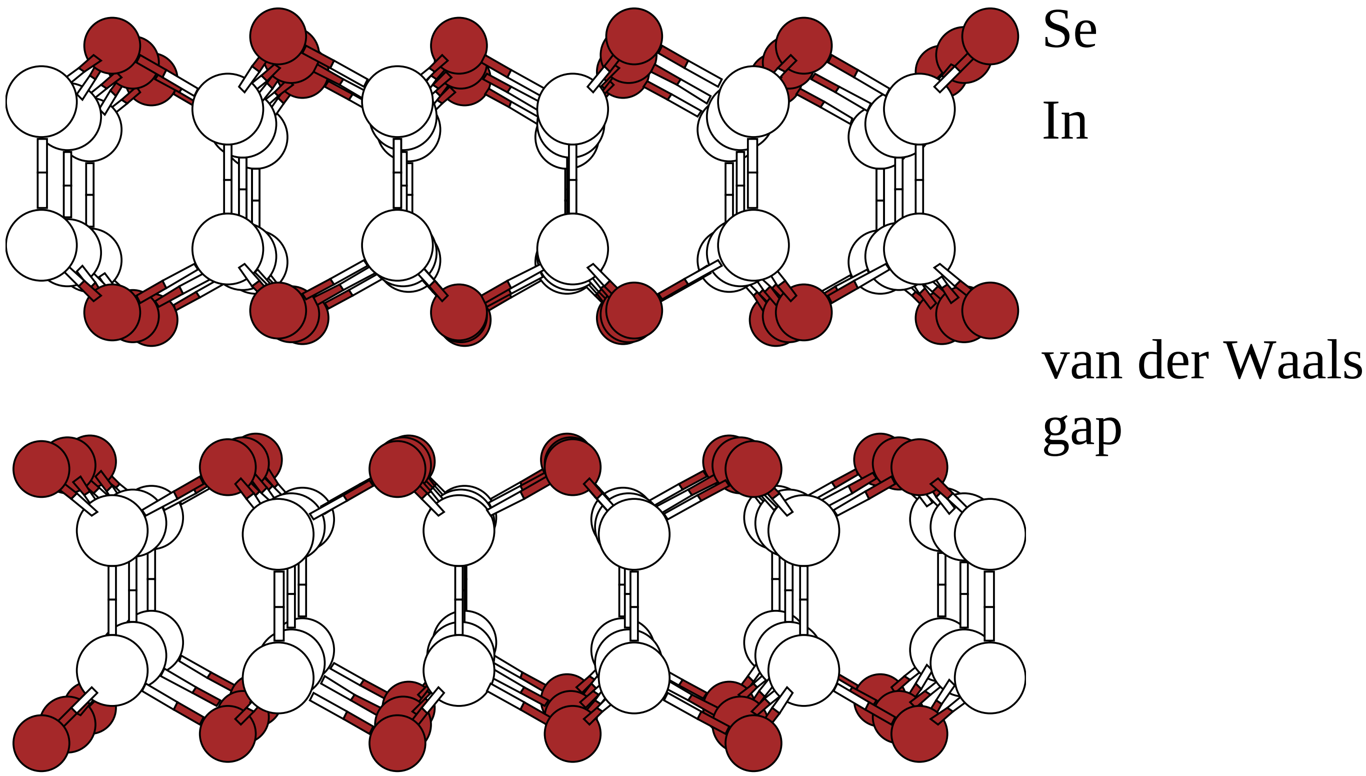
Decent Electrical Properties of InSe/GaSe Heterojunction Diodes



GaSe is natively p-type, while InSe is natively n-type.

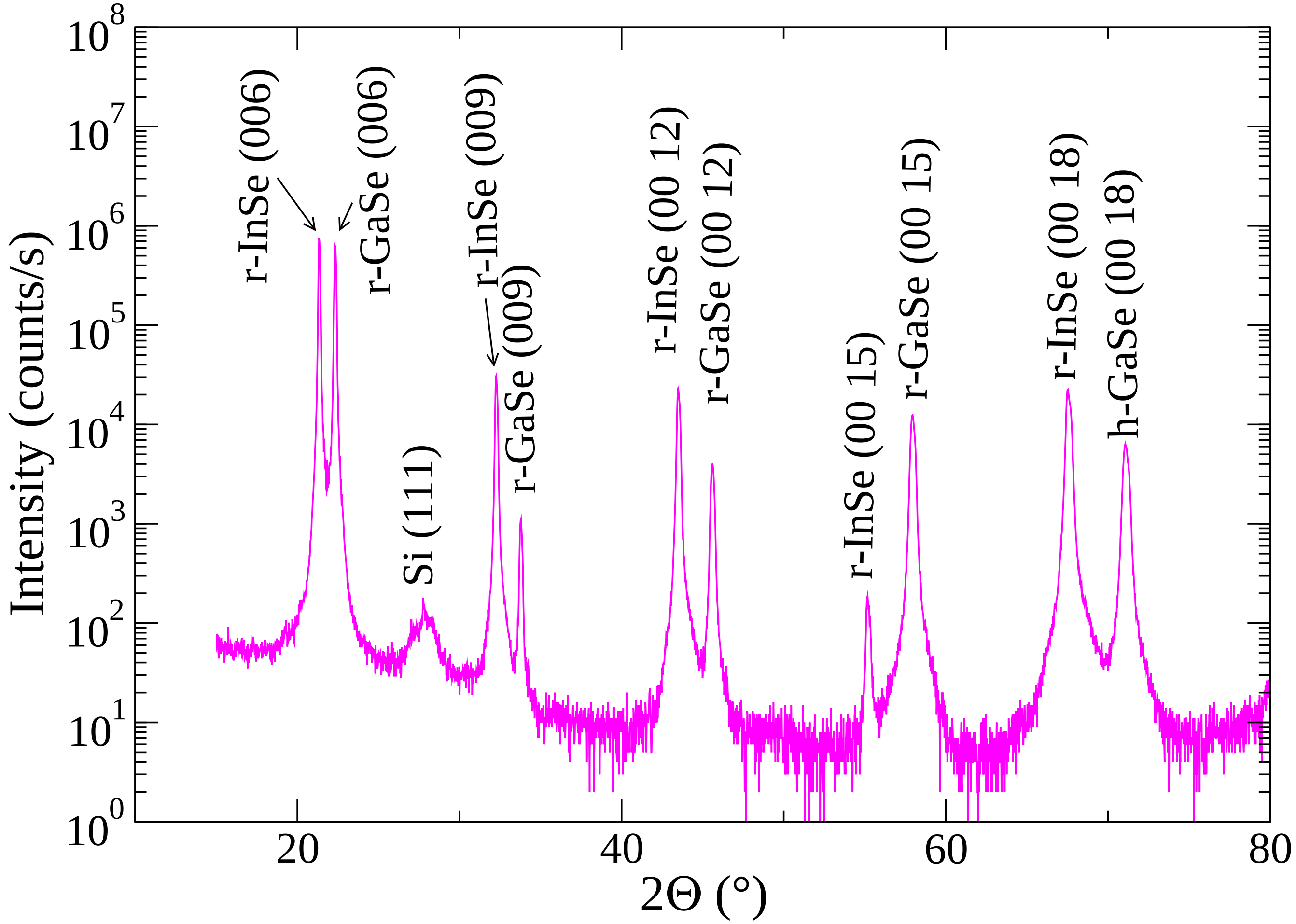
Collection efficiencies 5-10%.

Crystal Structure of III-VI InSe and GaSe



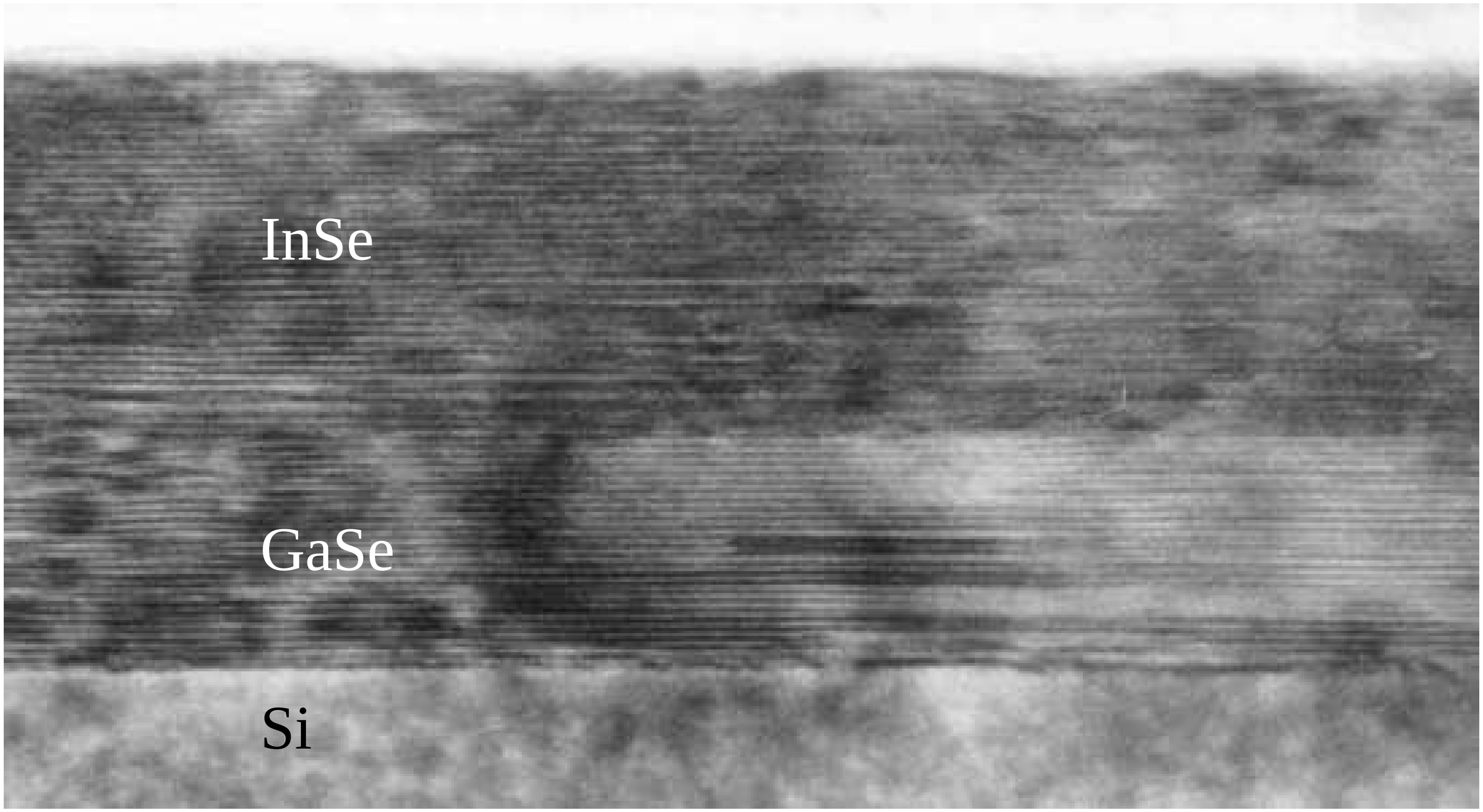
- GaSe grows epitaxially on Si(111) [Palmer *et al.*, JJAP 1993]
- InSe grows epitaxially on GaSe [Nakayama *et al.*, Surf. Sci. 1991]
- Substantial electrical and thermal anistropy in both materials.

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



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

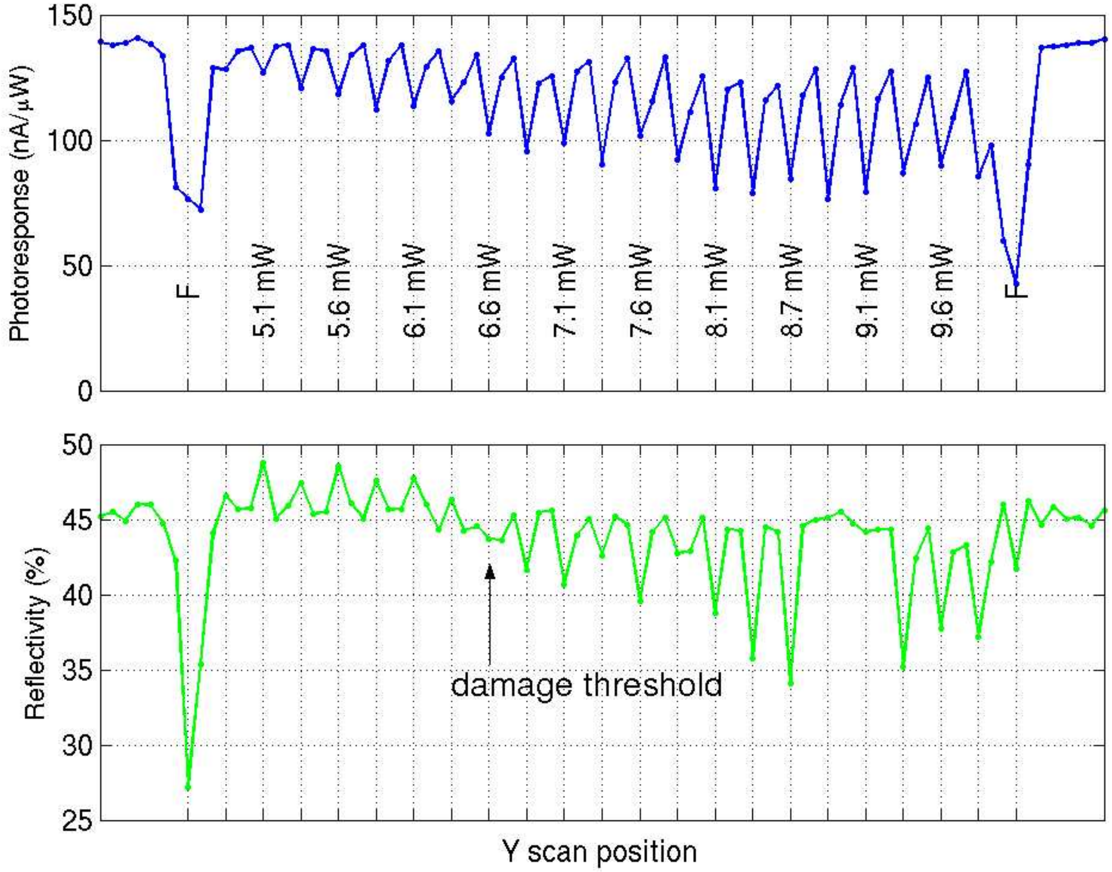
Good Quality Epitaxial InSe/GaSe/Si(111) Films



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.

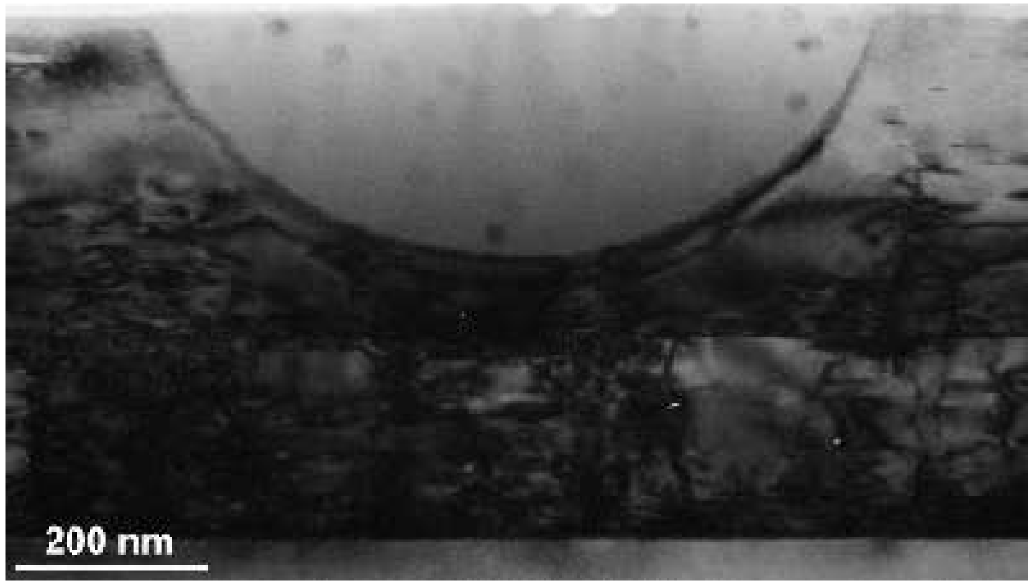
Making Amorphous Laser Marks



Diffraction-limited, 30 nS 488 nm laser marks.

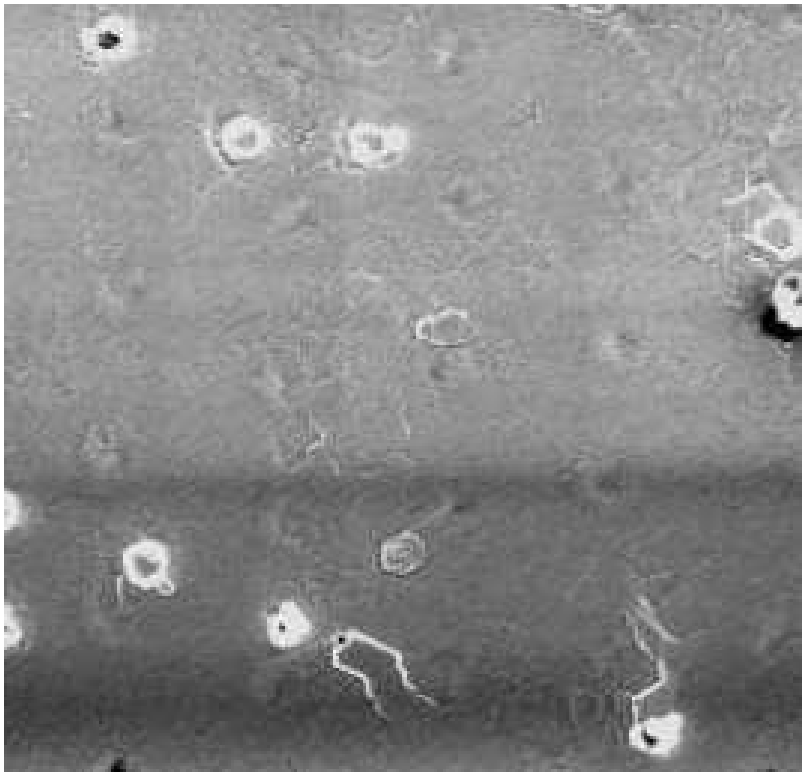
Reflectivity changes sign at damage threshold.

Amorphous Laser Marks

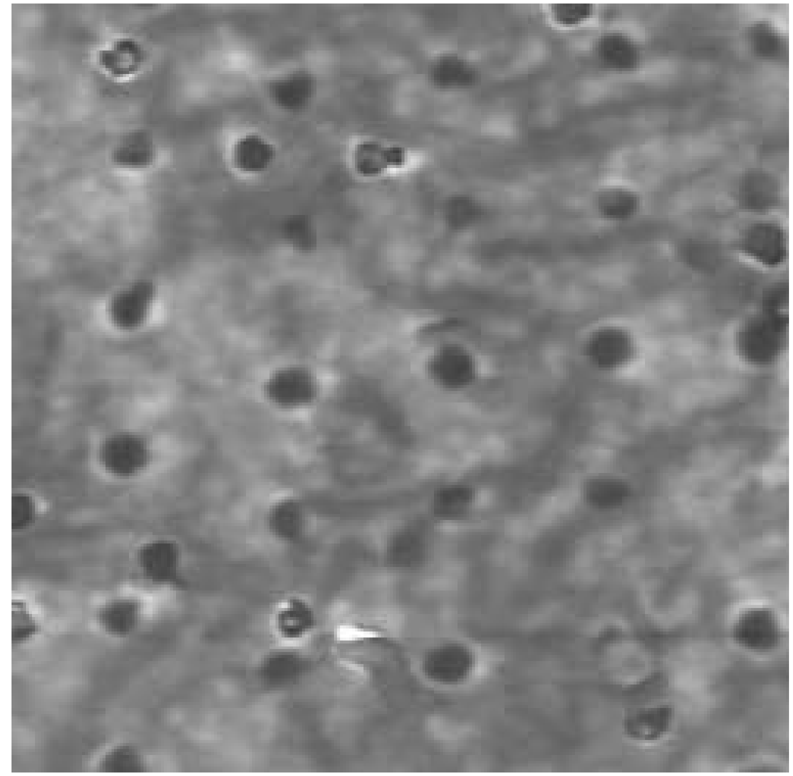


Laser used to simulate e-beam recording.

Electronic Contrast Observed without Surface Damage



SEM Image



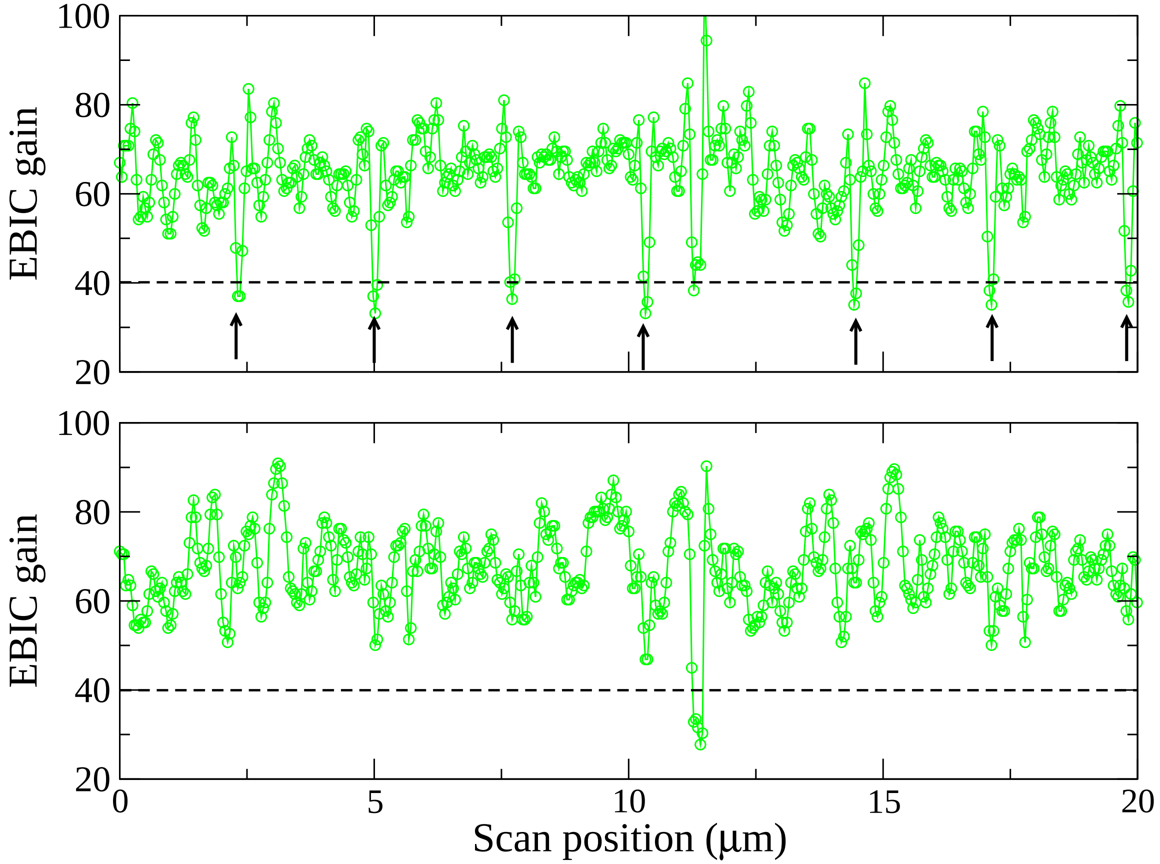
EBIC image

Marks are barely visible in SEM image. Spacing = 0.9 μm.

In inclusions cause large "media noise."

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

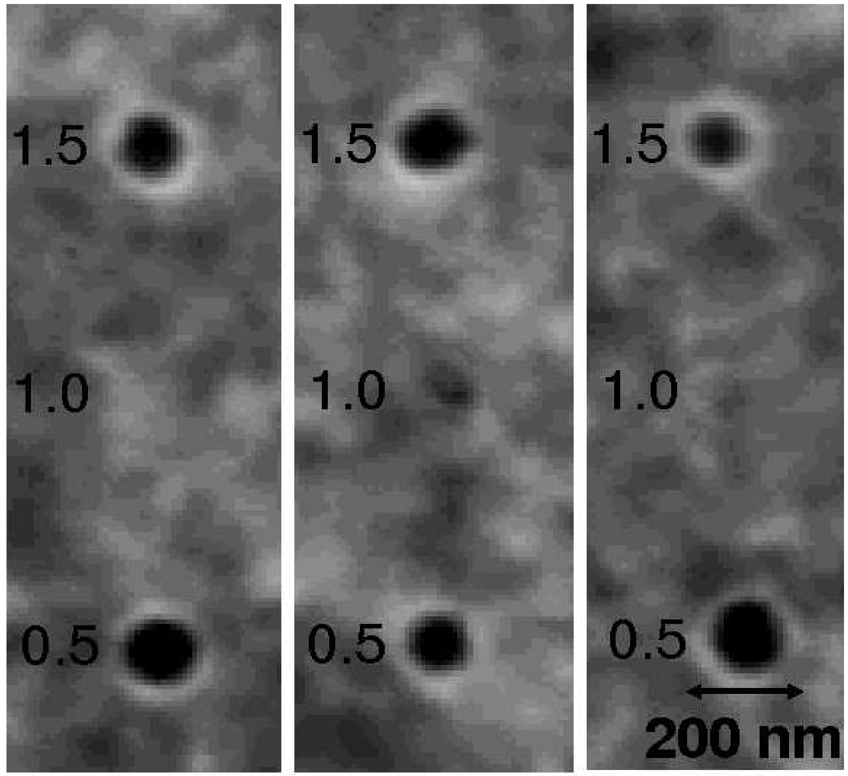
Oven Erasure of Amorphous Bits



Annealed at 300 °C for 5 minutes.

All amorphous bits have a gain < 40 before annealing and ≥ 50 afterwards.

Erasure without Surface Damage

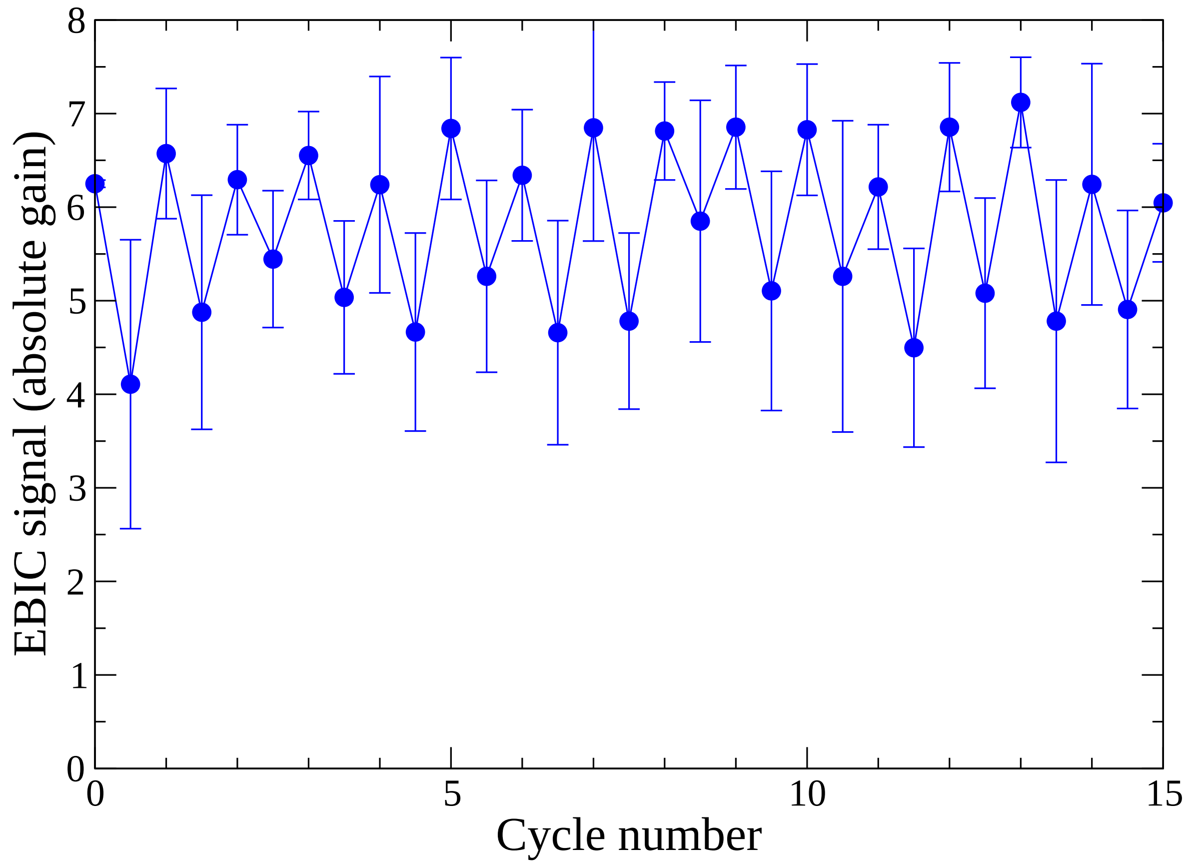


0.5 = Write pulse only; 1.0 = Write/Erase; 1.5 = WEW ...

W = 4.7 mW, 30 nS; E = 1.8 mW, 1 mS.

Up to 100 cycles with only minor degradation.

15 Cycles without Degradation Achieved



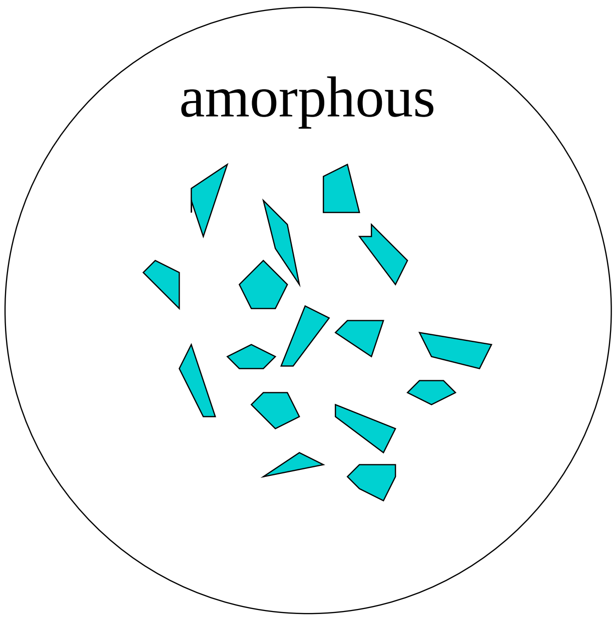
Points indicate values obtained by averaging across rows of a matrix.

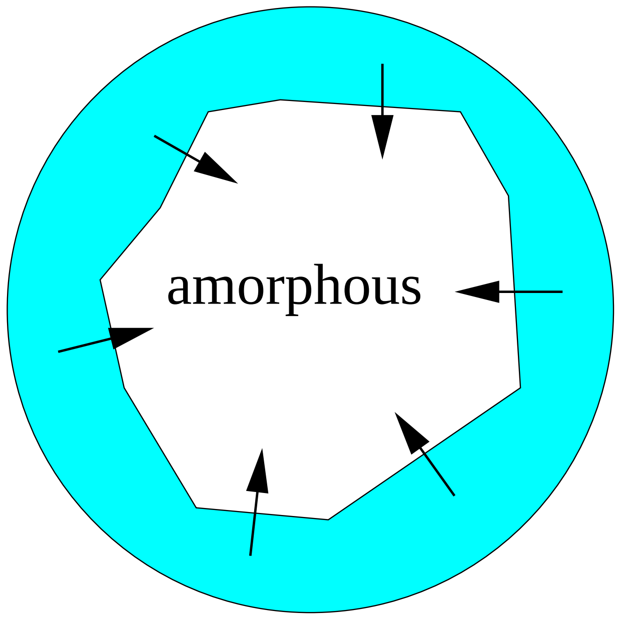
Optimize contrast via improved film growth, film thickness, cap layer parameters, beam energy and device bias.

Scaling of Erasure Time Depends on Recrystallization Mode

Homogeneous nucleation plus growth

Regrowth from crystalline matrix without nucleation

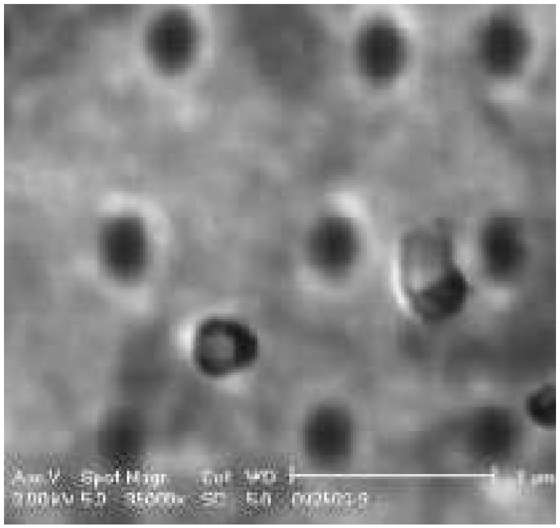




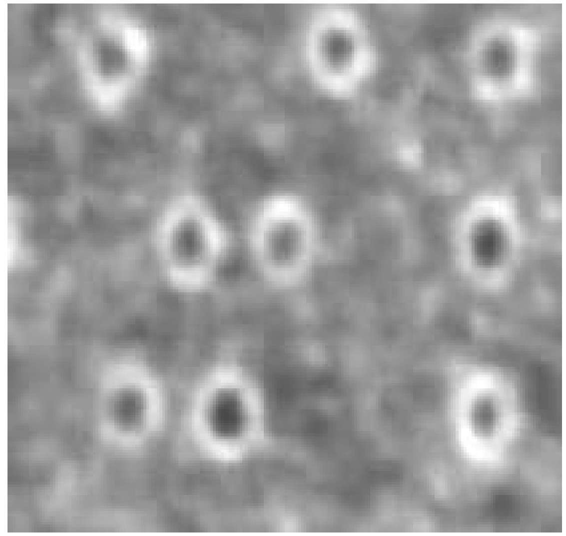
Like GeSbTe

Like InAgSbTe

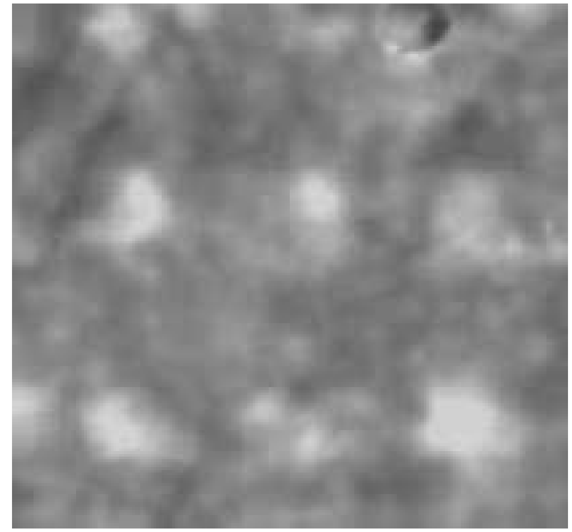
Some Evidence for Regrowth from the Matrix



Write pulse only



Write + 10 μS erase

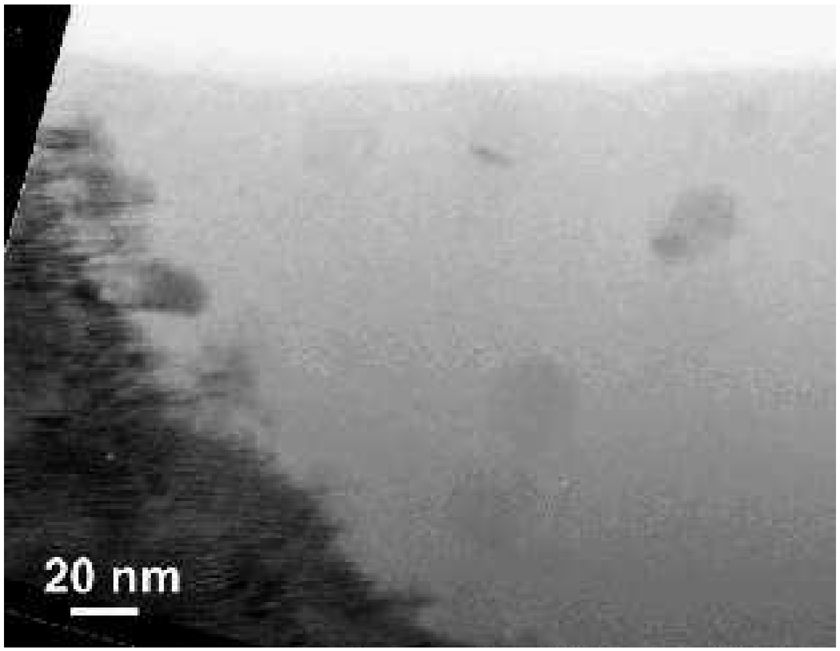


Write + 100 μS erase

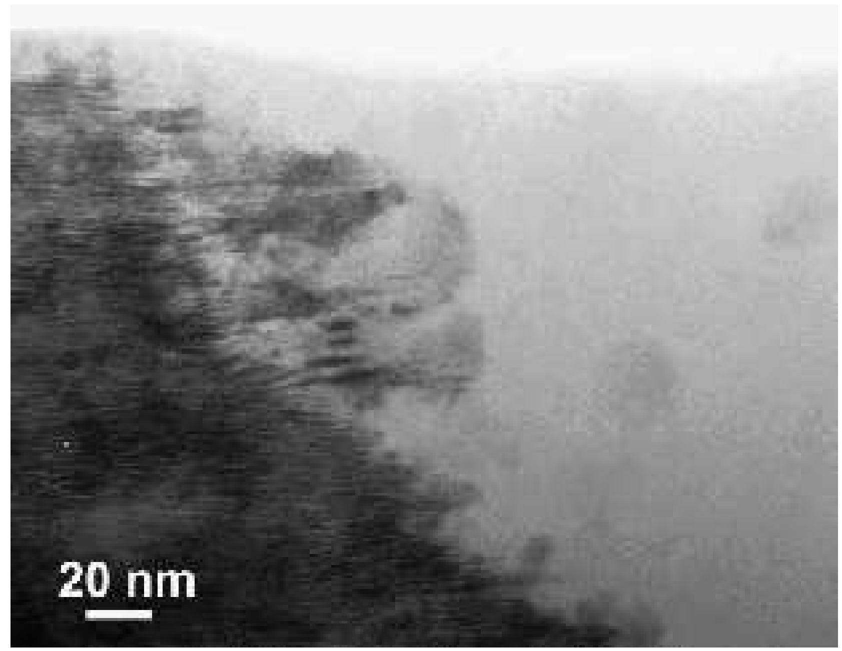
As erase pulse lengthens, bright ring grows inward.

Final mark has larger signal than surrounding matrix.

In Situ TEM Recrystallization Occurs from Mark Edge



Write pulse only

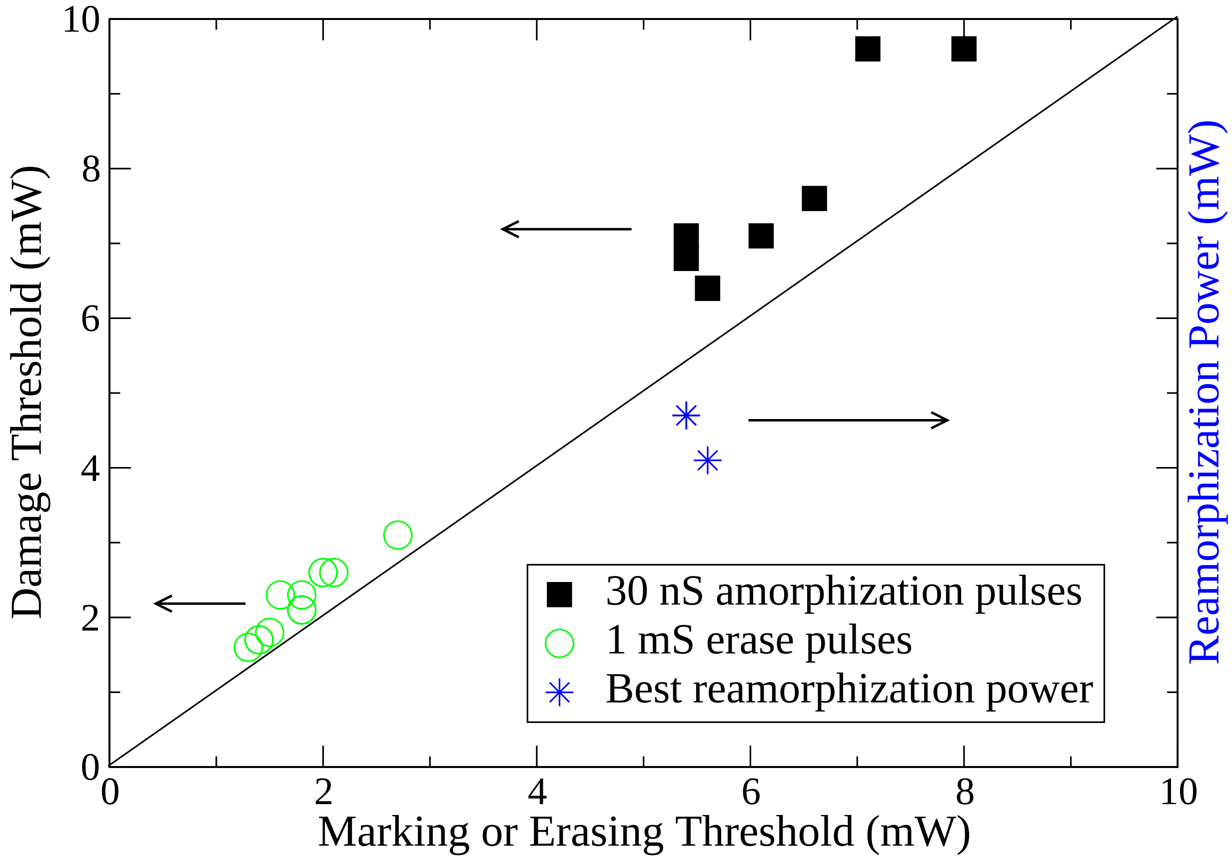


Write + 1 S irradiation

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



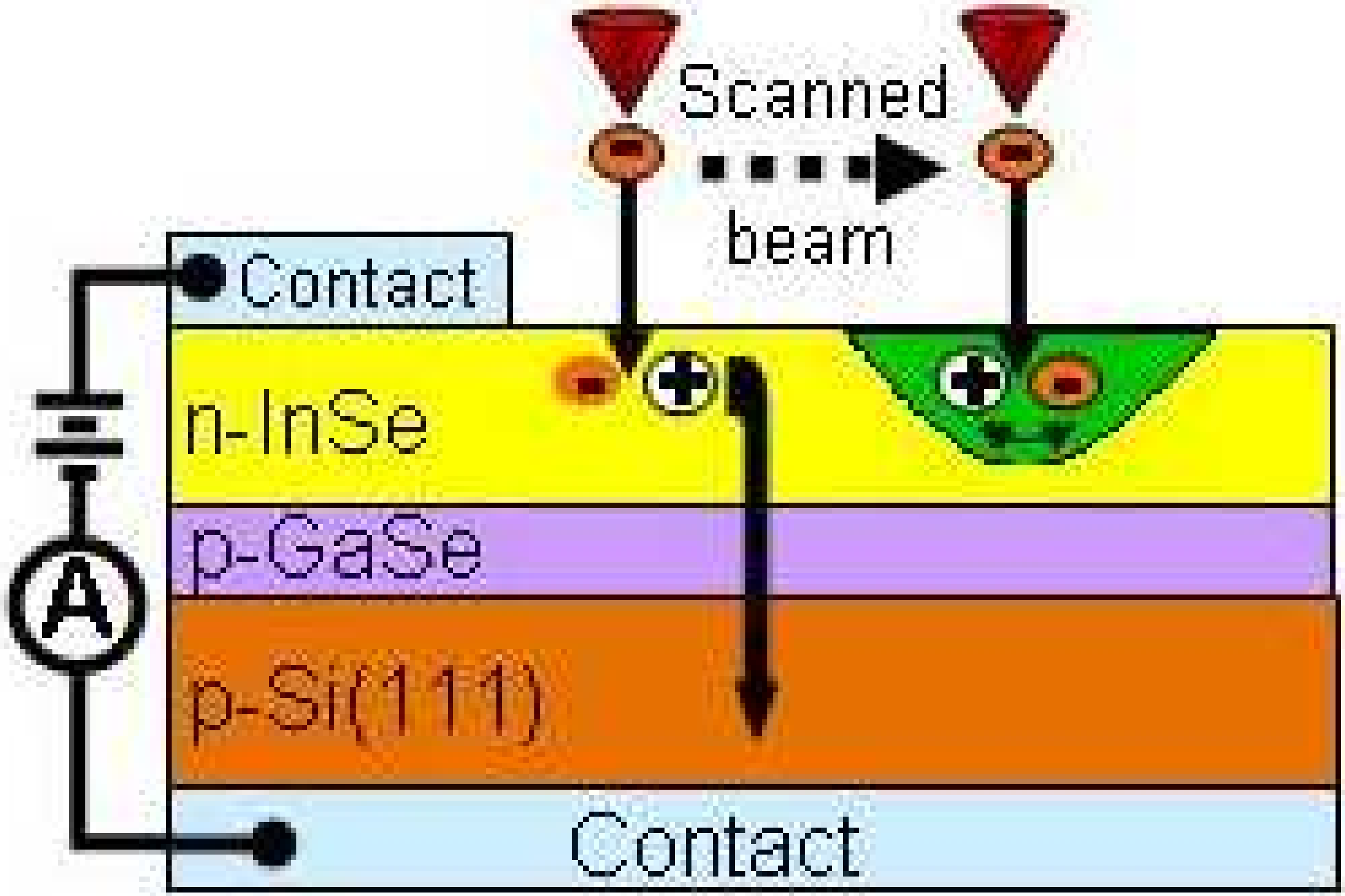
Larger margins correspond to thicker cap layers.

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

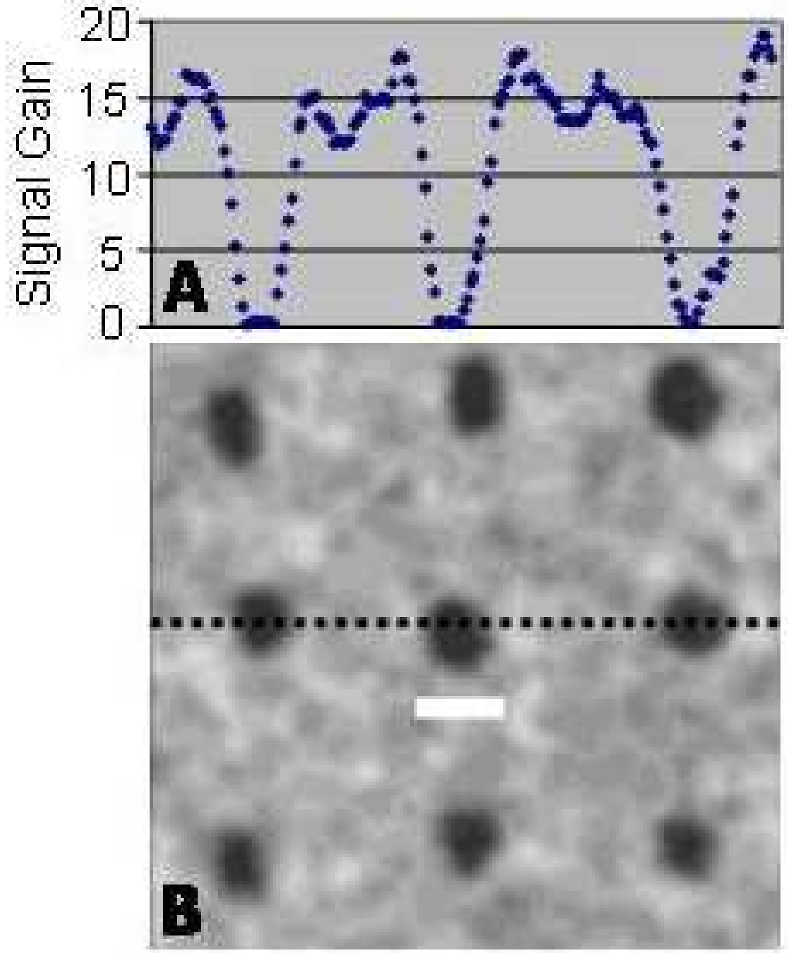
Summary

- 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.

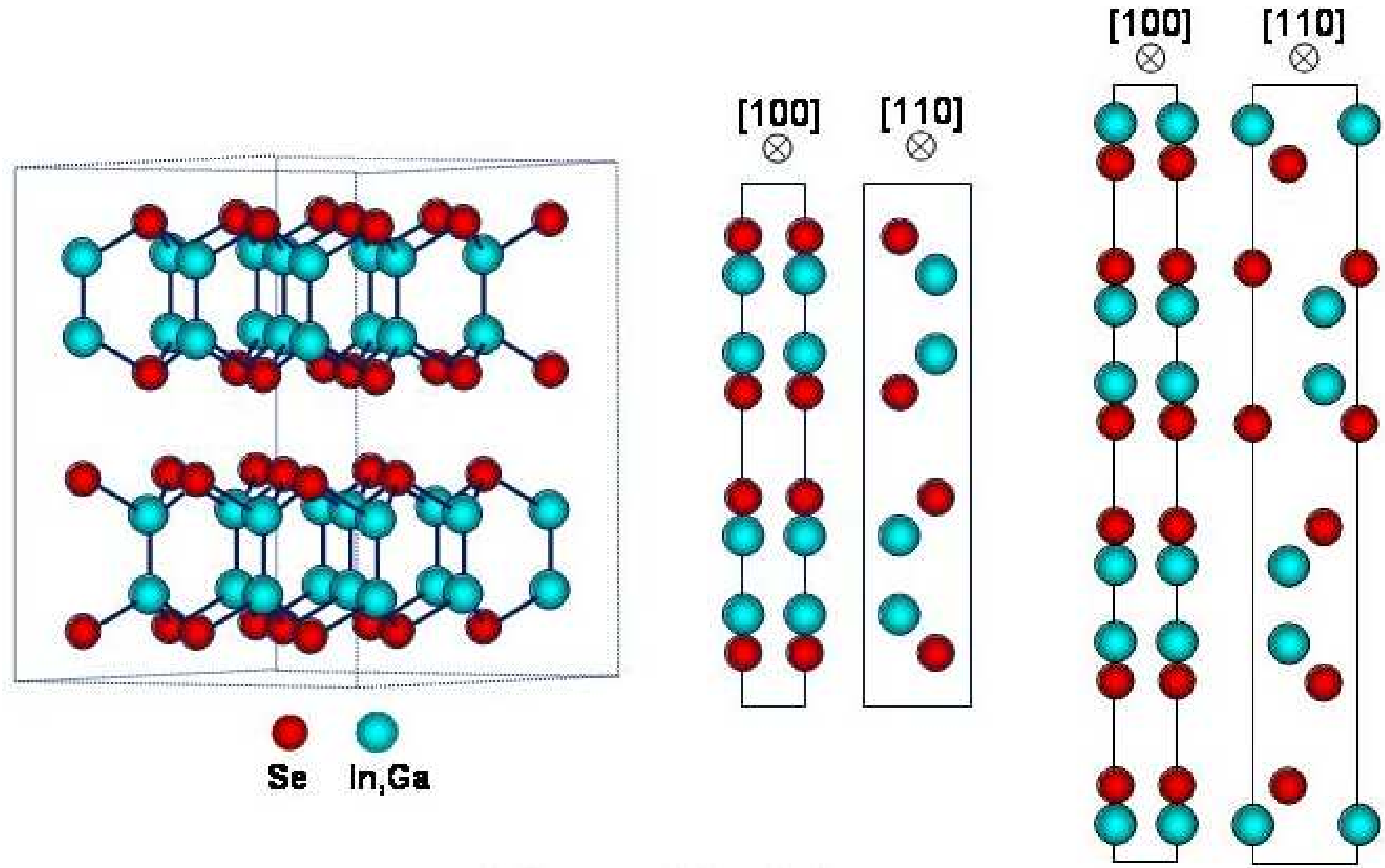
Data Readback Concept



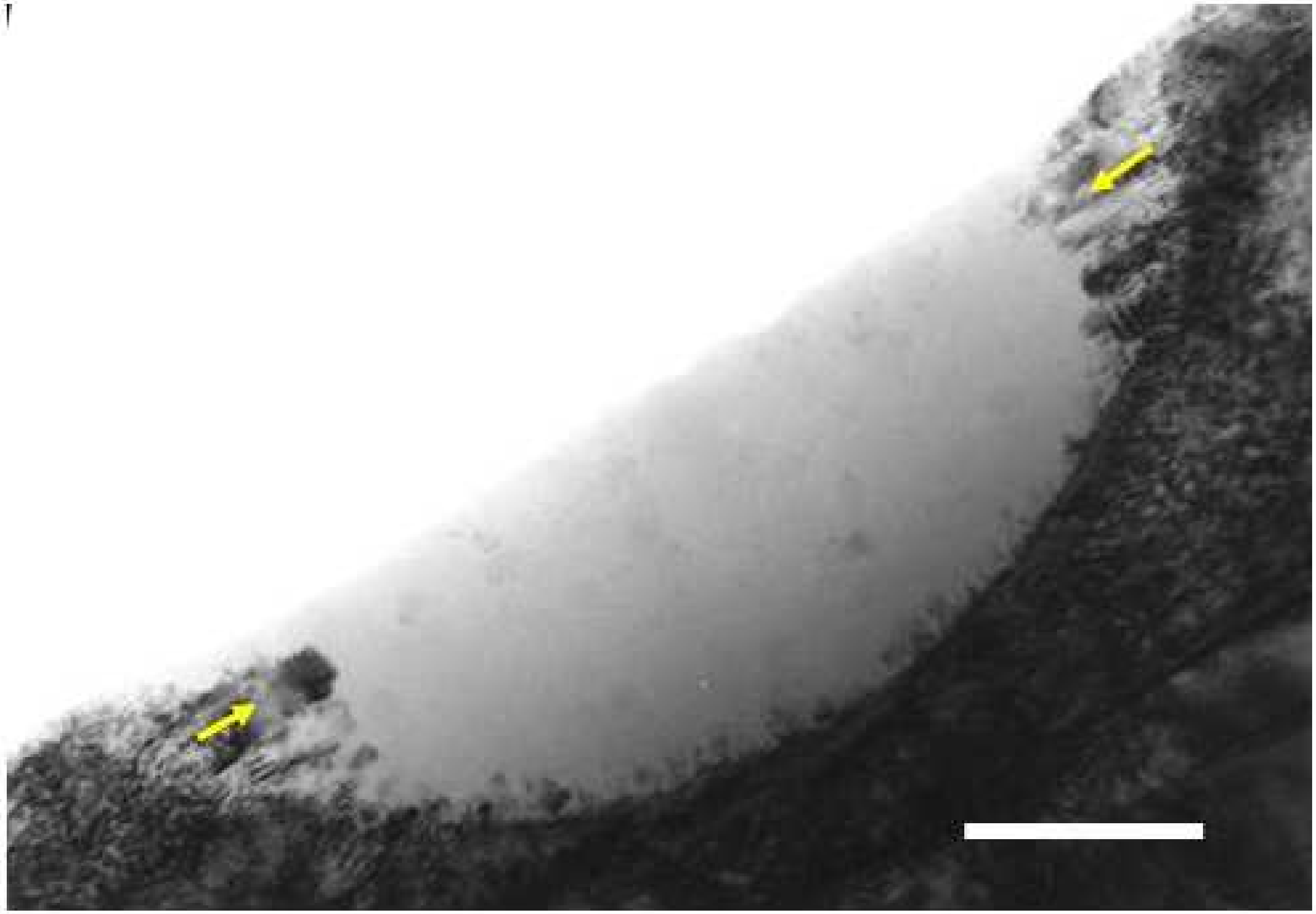
Electron-Beam Readback of a Data Track



InSe and GaSe Crystal Structure



Larger View of E-beam Recrystallization at Edges



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