Submicron Amorphization and Recrystallization of III-VI Epitaxial Semiconductor Diodes

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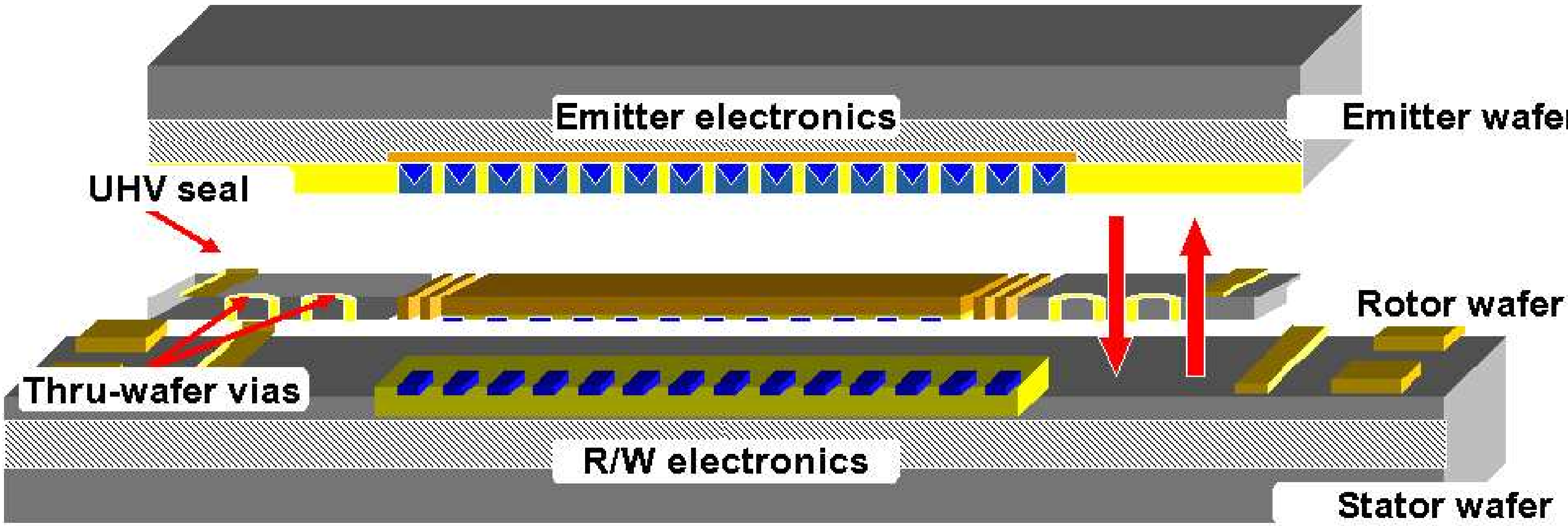
- Rationale for electron-beam scanned-probe data storage
- Epitaxial III-VI semiconductor diode properties
- Reading, writing and erasing amorphous bits

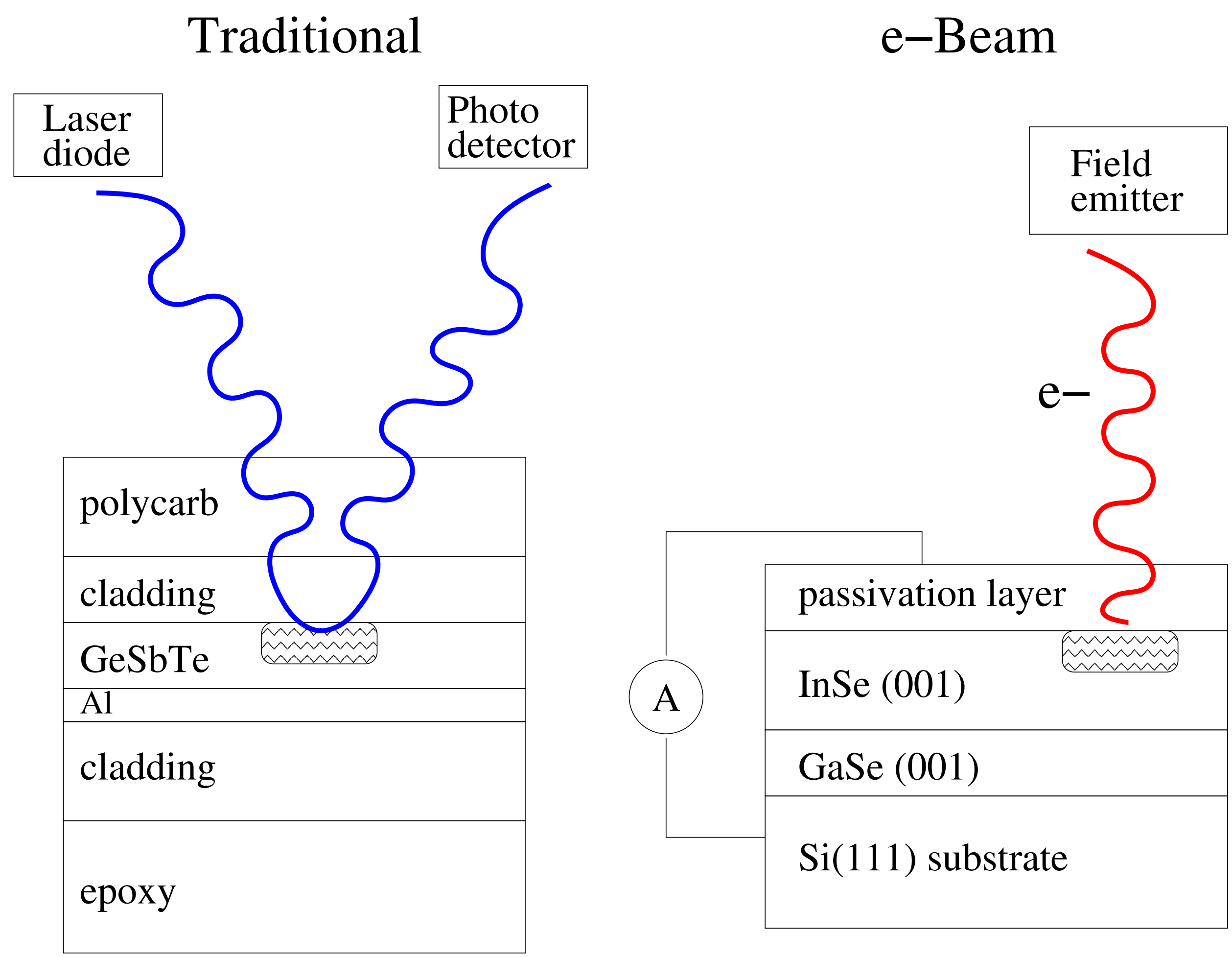
Electron-Beam Recording on Phase-Change Media



Features:

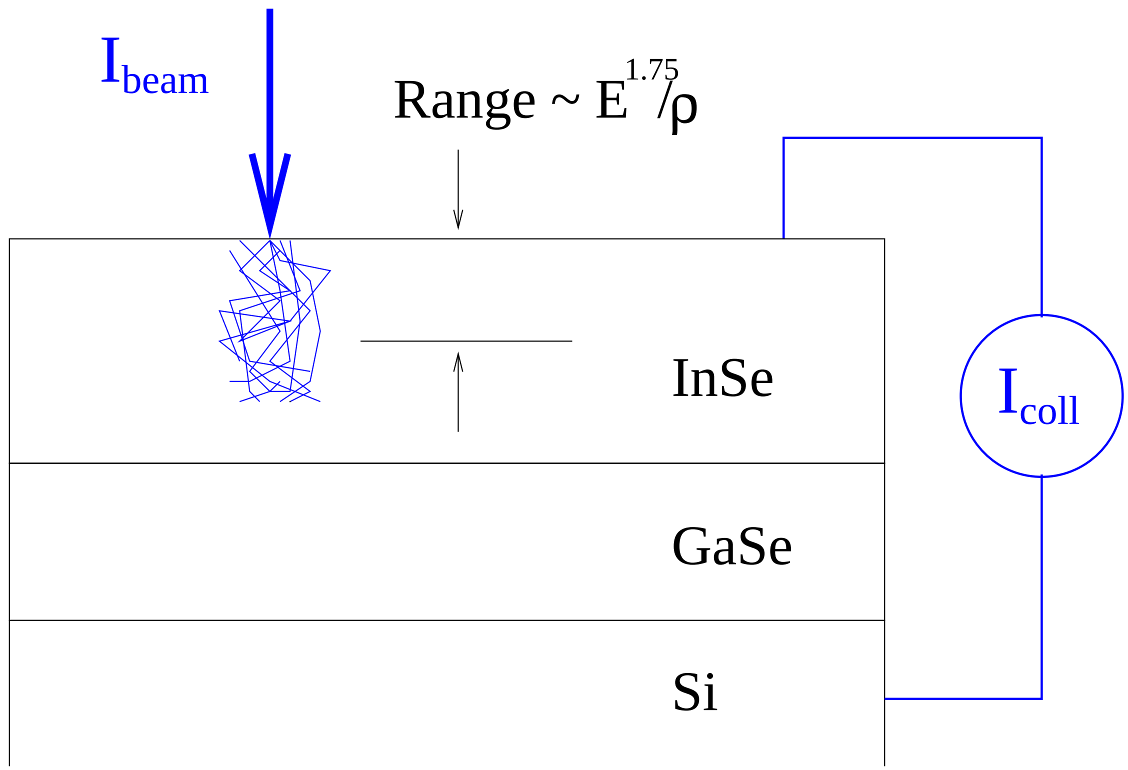
- Unpatterned media scanned in two dimensions;
- Reading and writing via electron-beam field emitters in vacuum;
- Phase-change media for data storage.

Optical vs. Electron-Beam Recording



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

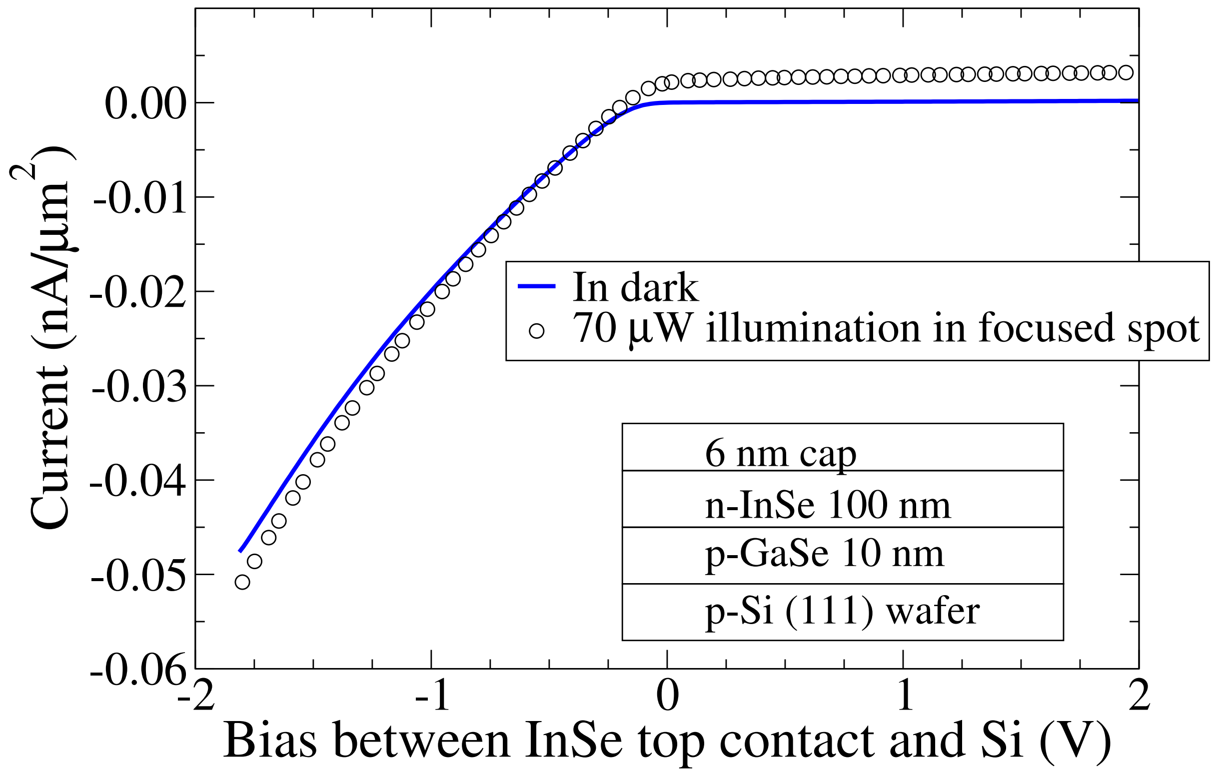
Electron-Beam Induced Current (EBIC) with keV Electrons Gives Gain



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

Gain $\equiv I_{coll}/I_{beam}$, theoretically $\approx$200 at 700 eV.

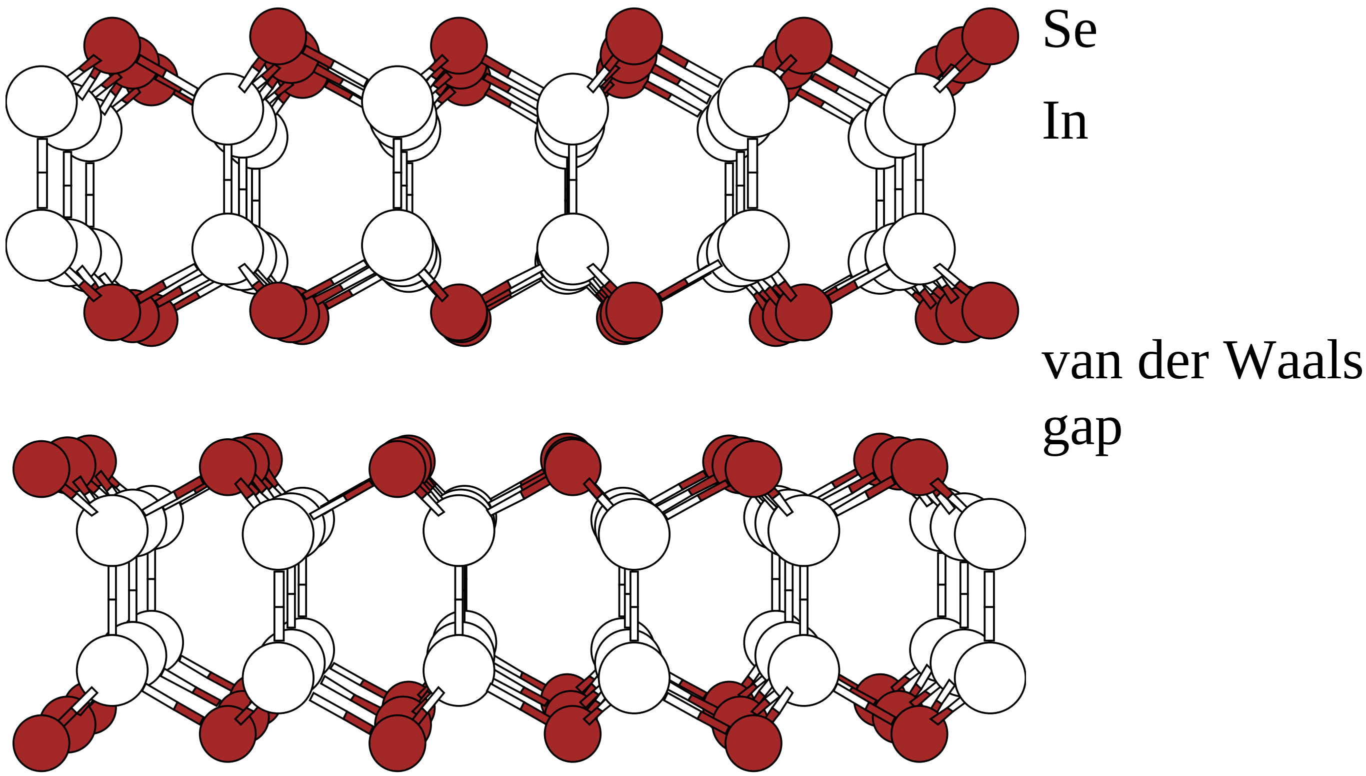
Decent Electrical Properties of InSe/GaSe Heterojunction Diodes



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

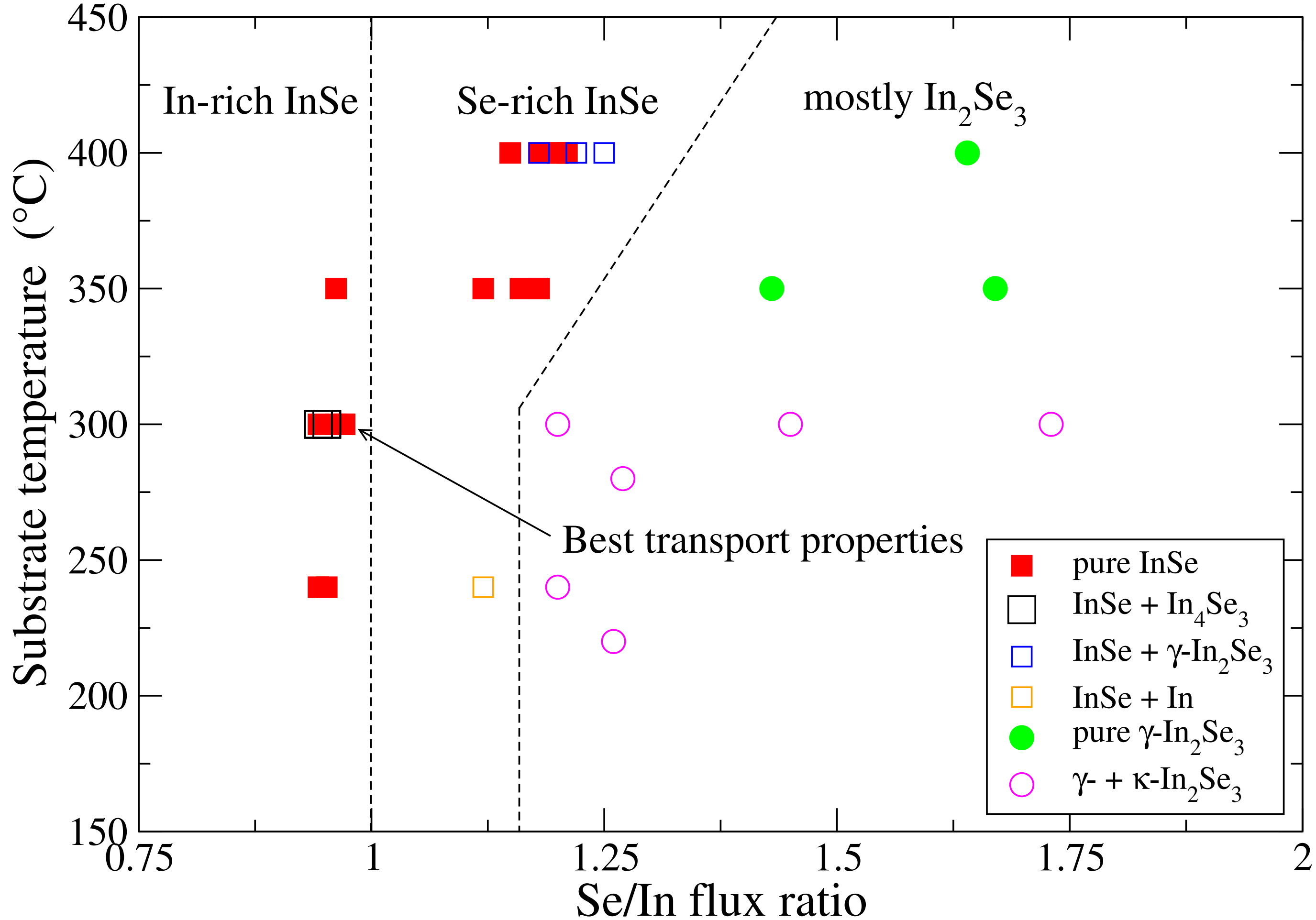
Collection efficiencies > 20%.

Crystal Structure of III-VI InSe and GaSe



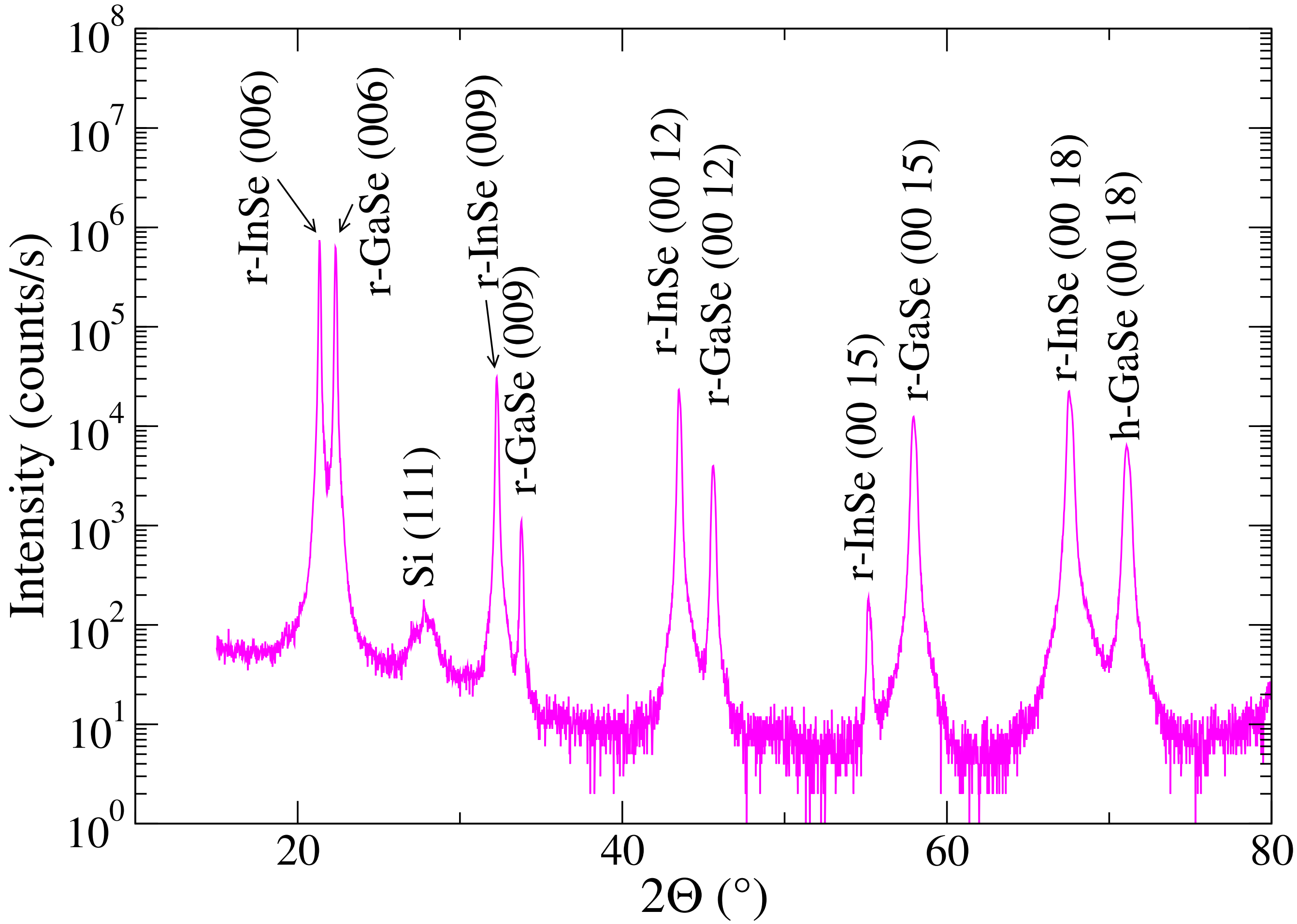
- GaSe grows epitaxially on Si(111) [Palmer *et al.*, JJAP 1993]
- InSe grows epitaxially on GaSe [Nakayama *et al.*, Surf. Sci. 1991]
- Substantial electrical and thermal anistropy in both materials.

MBE Growth Study of InSe Films



Best films are single-phase by XRD but have In_4Se_3 according to PL.

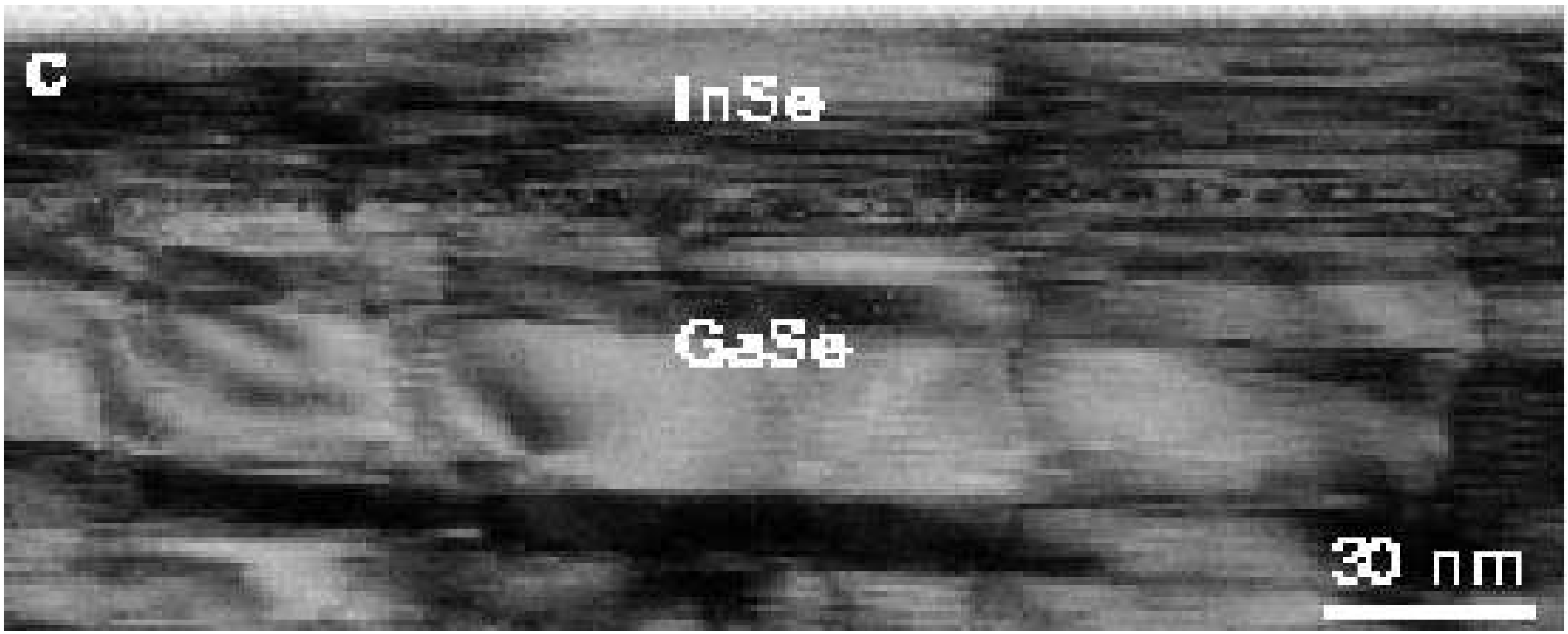
Good Quality Epitaxial InSe/GaSe/Si(111) Films



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

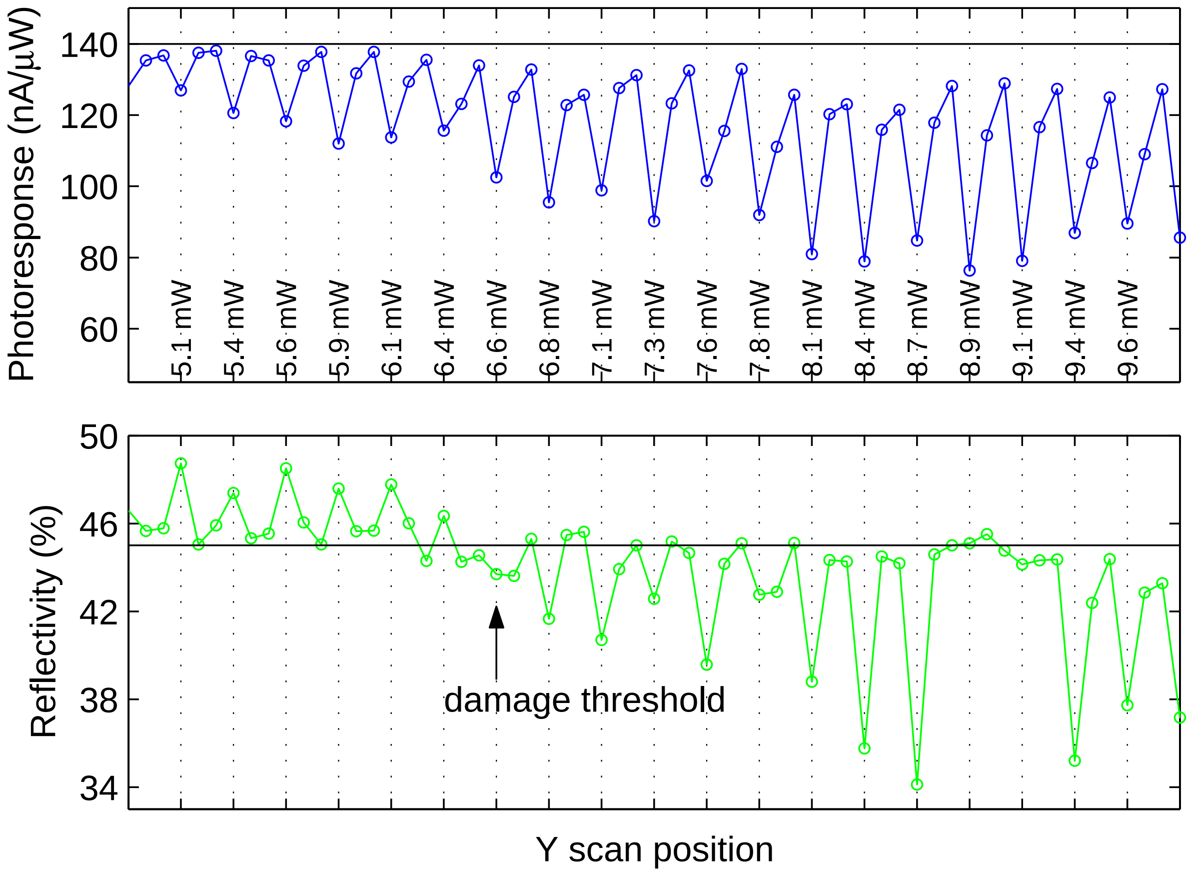
InSe/GaSe Films are Defect-Tolerant like GaN

Films have twins, stacking faults and threading dislocations.



Highly defected films have reasonable device performance.

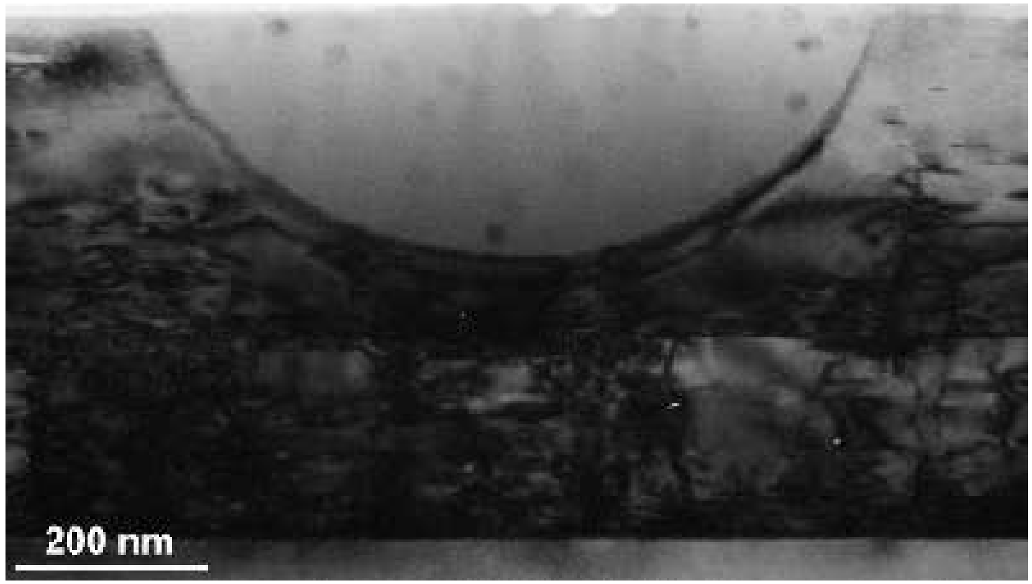
Write Parameters Optimized via Systematic Testing



Diffraction-limited, 30 nS 488 nm laser marks.

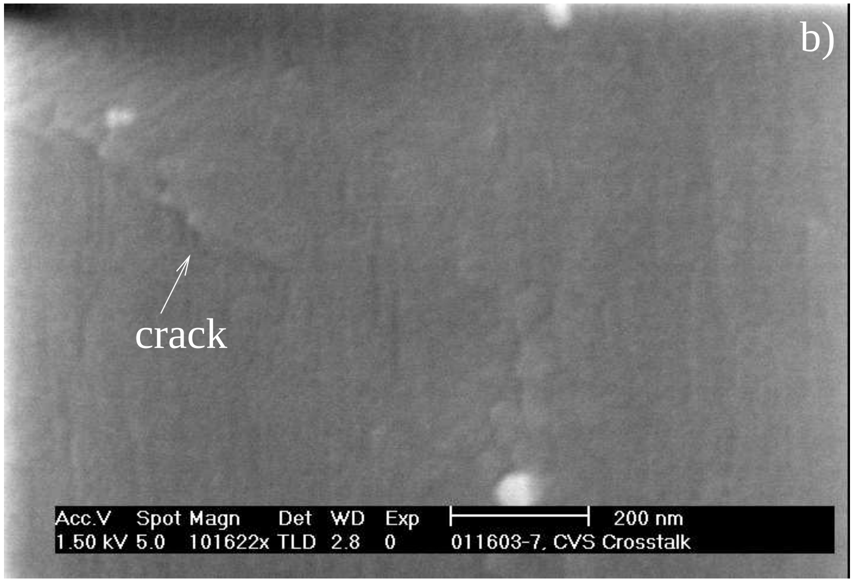
Reflectivity changes sign at damage threshold.

Laser Marked Regions are Amorphous

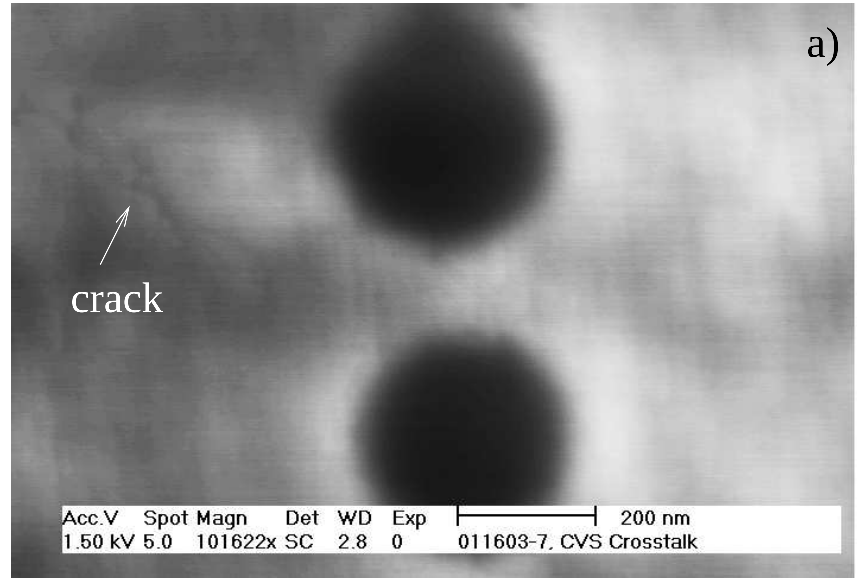


Short laser pulses used to simulate e-beam recording.

Electronic Contrast Observed without Surface Damage



SEM Image

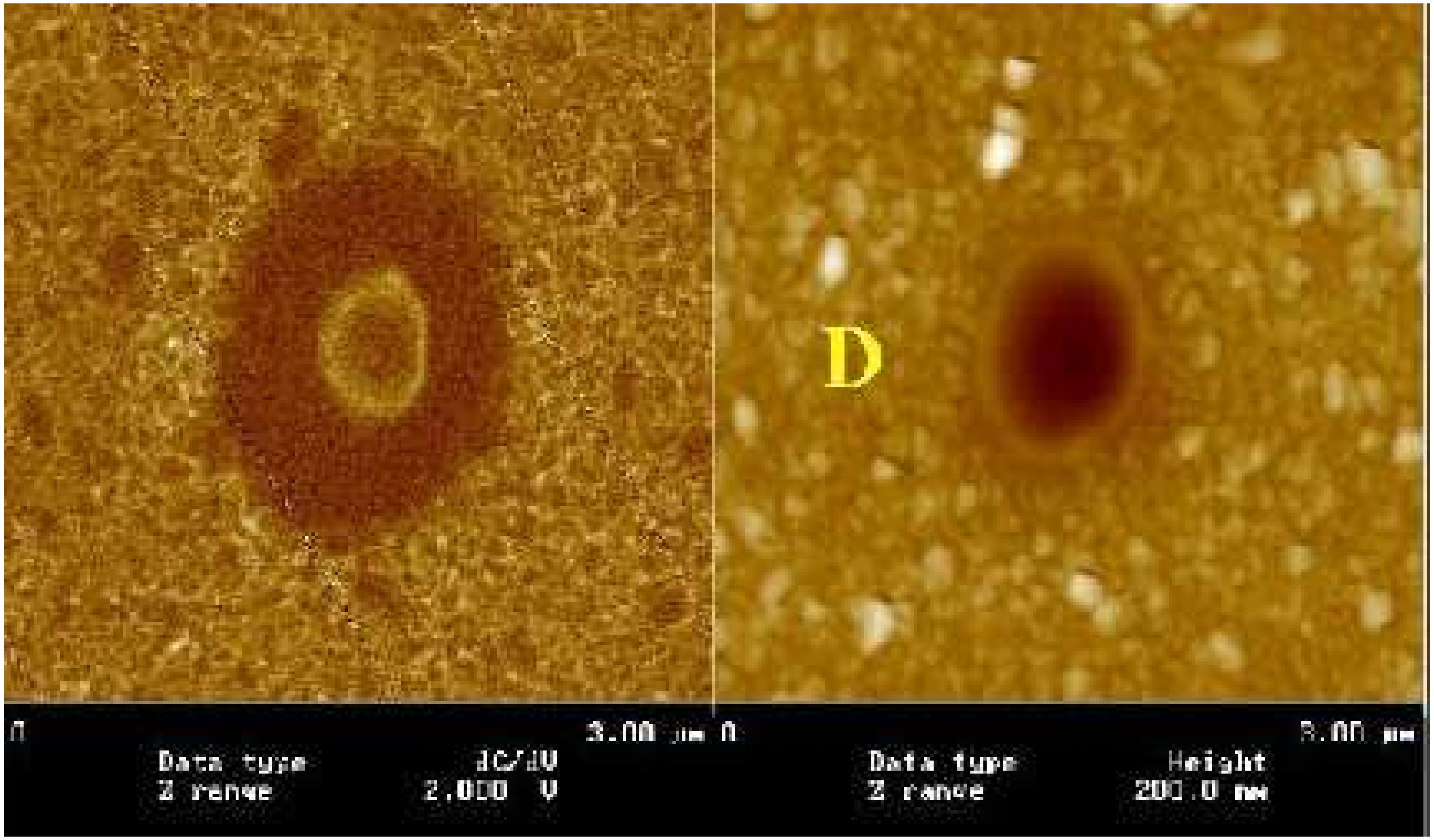


EBIC (collection efficiency) map

Marks are barely visible in SEM image.

Pulsewidth $<$ thermal equilibration time gives mark diameter 100-200 nm.

Origin of Contrast in Bits is Poorly Understood

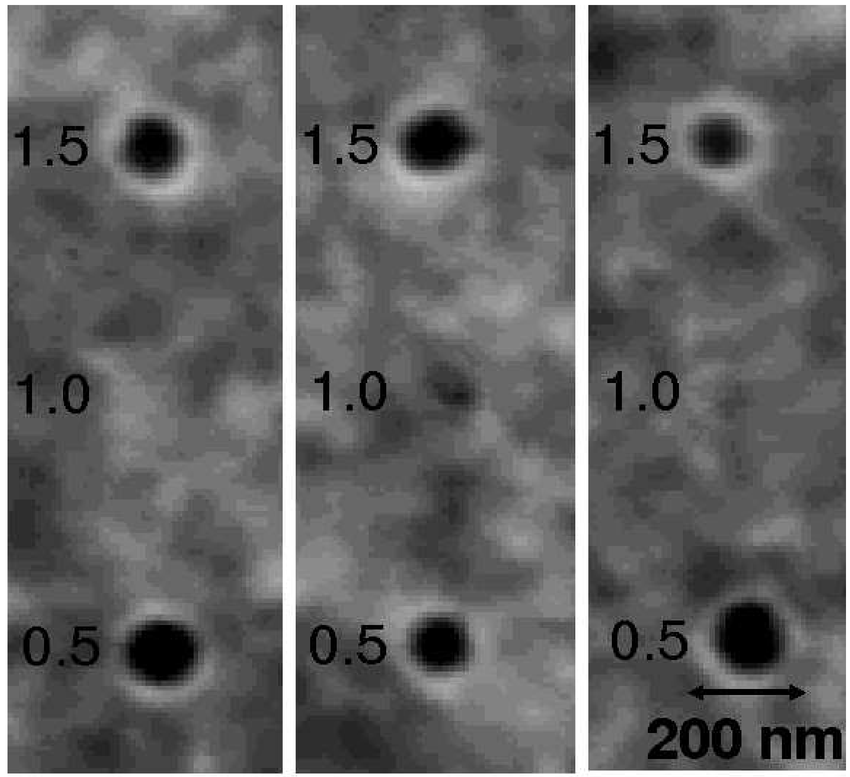


Scanned capacitance image Topographic image

The schubweg ($\mu\tau E$) differs between amorphous bits and crystalline matrix.

Erasure without Surface Damage

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

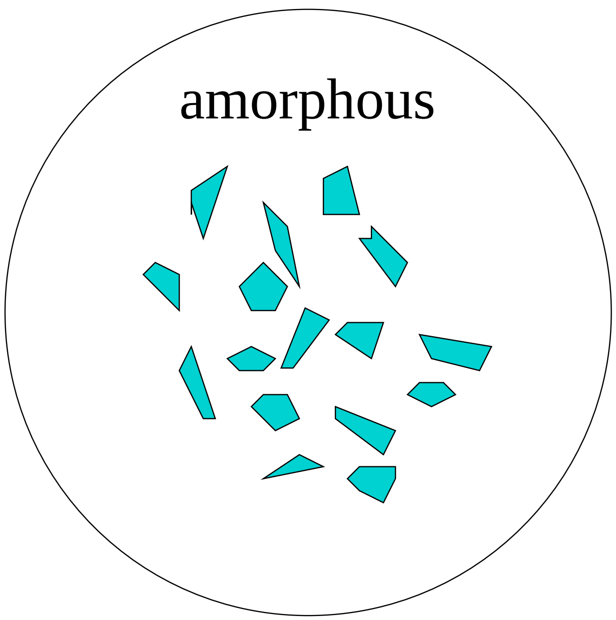


EBIC (collection efficiency map) images

Up to 100 cycles with only minor degradation.

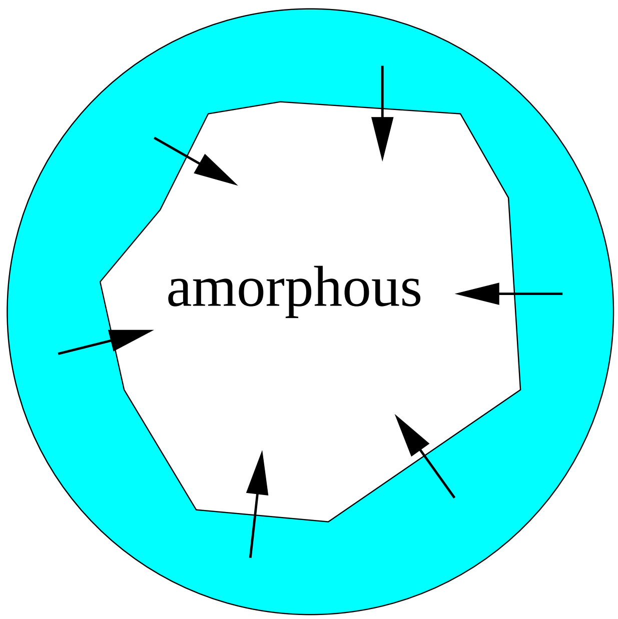
Scaling of Erasure Time Depends on Recrystallization Mode

Homogeneous nucleation plus growth



Like GeSbTe

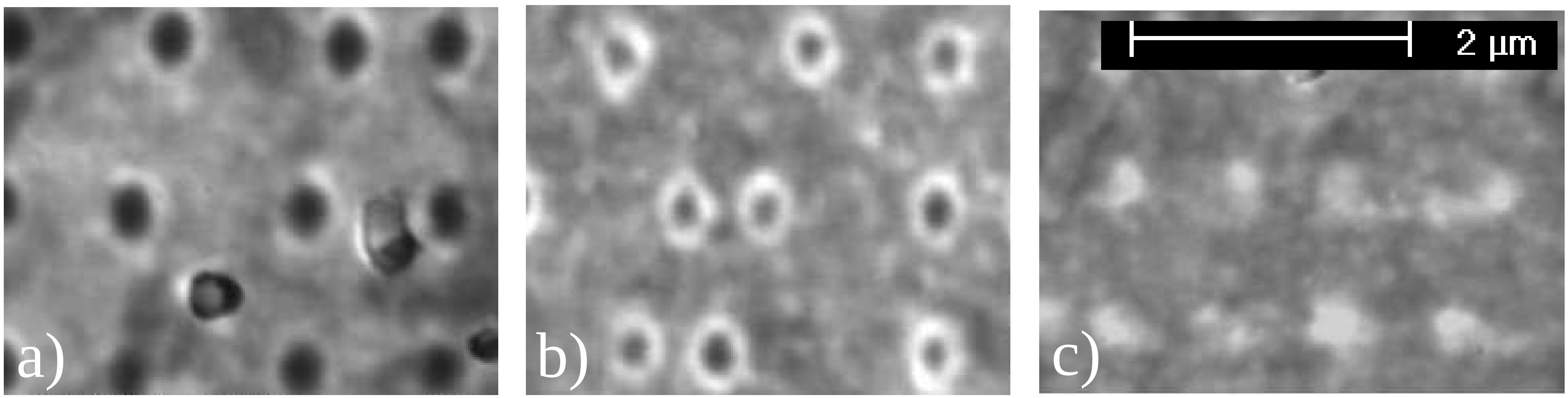
Regrowth from crystalline matrix without nucleation



Like InAgSbTe

Some Evidence for Regrowth from the Matrix

Write pulse only　　Write + 10 μS erase　　Write + 100 μS erase

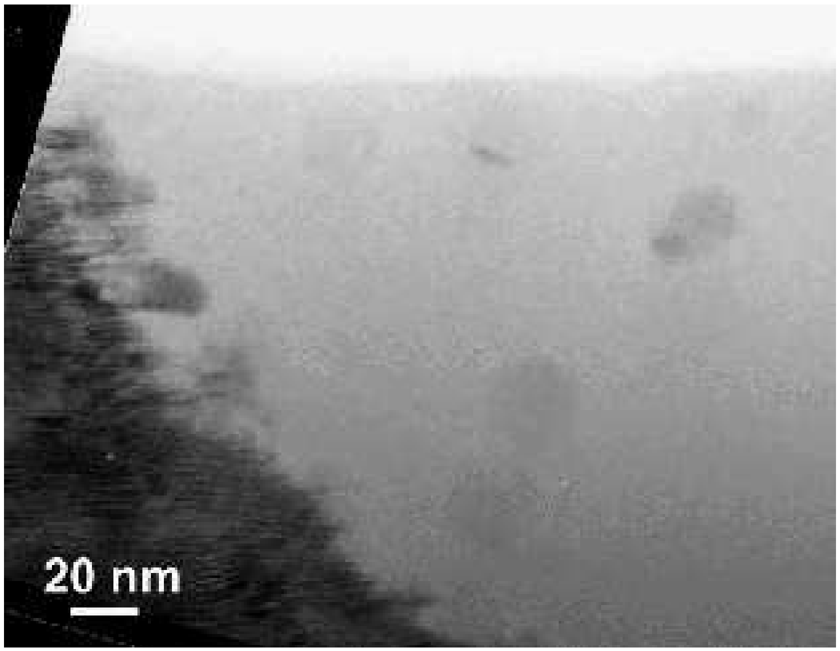


EBIC (collection efficiency map) images

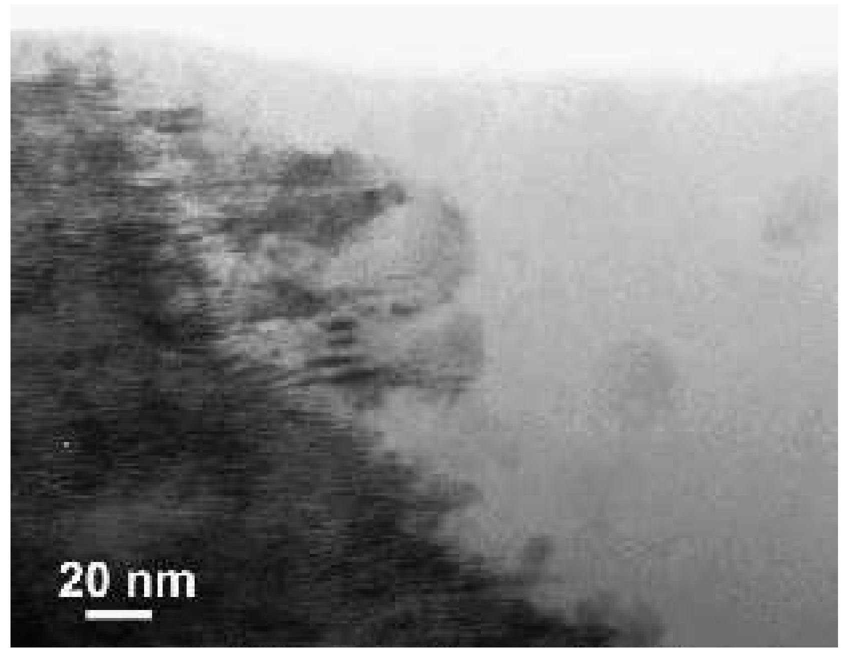
As erase pulse lengthens, bright ring grows inward.

Final erased mark has larger signal than surrounding matrix.

In Situ TEM Recrystallization Occurs from Mark Edge



Write pulse only



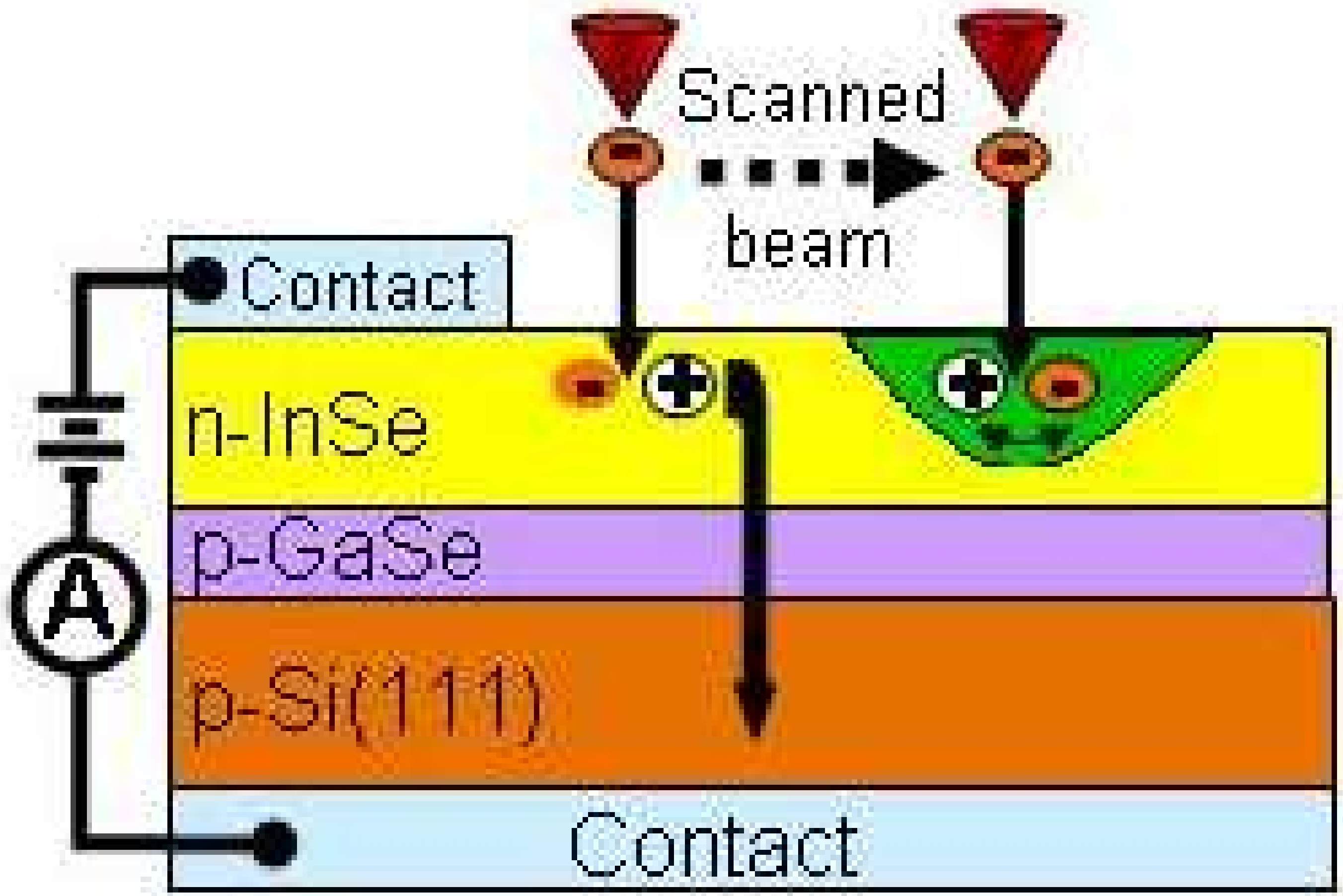
Write + 1 S irradiation

Growth-dominant behavior can occur under some circumstances.

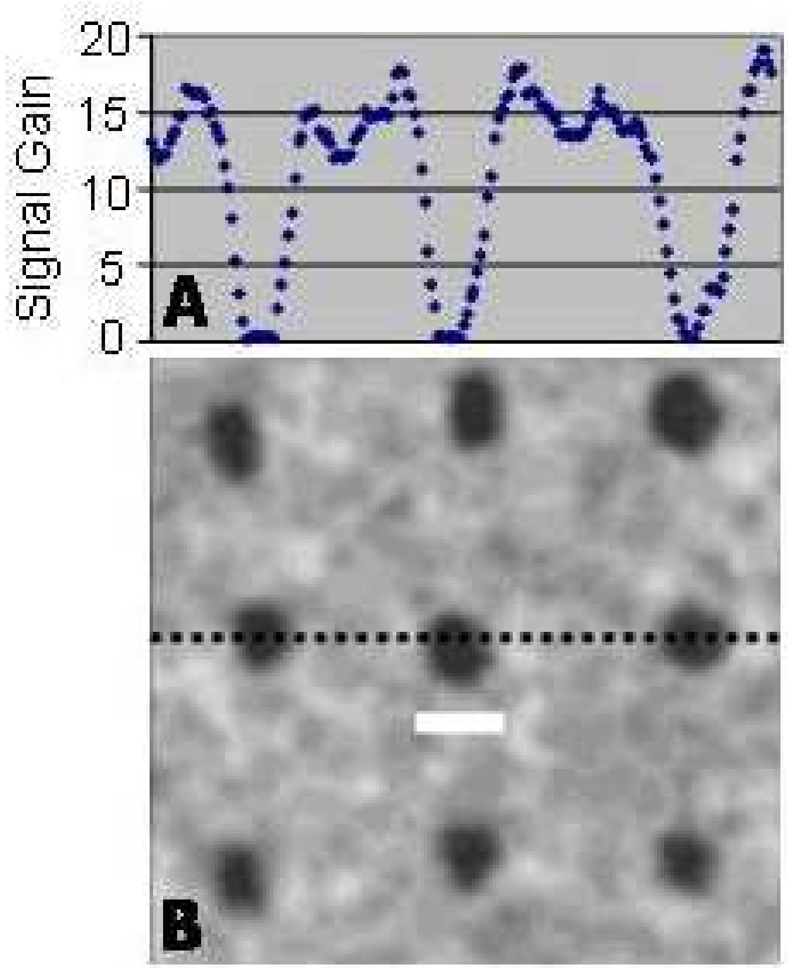
Summary

- 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.
- Best write and erase parameters were found via automated, systematic variation of parameters.
- Optimization of film growth, device design and read/write strategy has a long way to go.

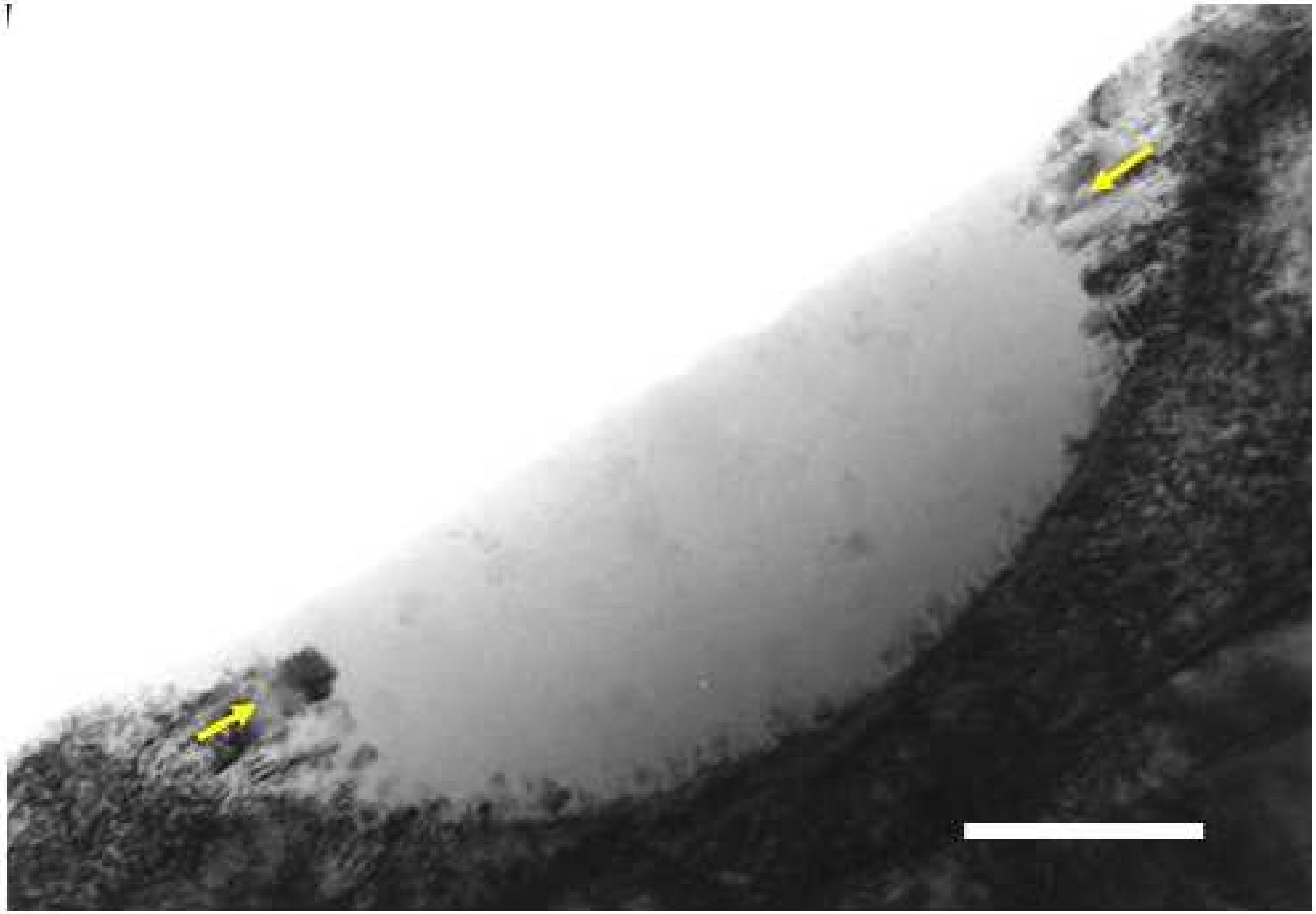
Data Readback Concept



Electron-Beam Readback of a Data Track



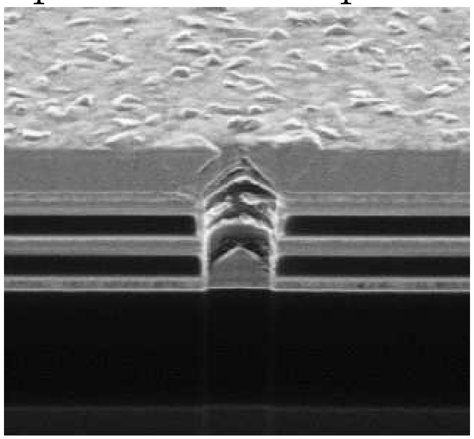
Larger View of E-beam Recrystallization at Edges



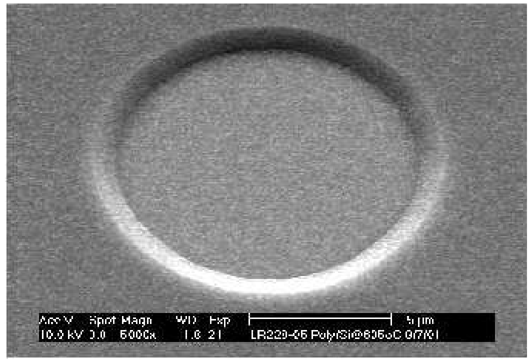
Diameter of bit at surface is about 800 nm (much larger than erasable bits).

Electron-Beam Emitters for Read/Write

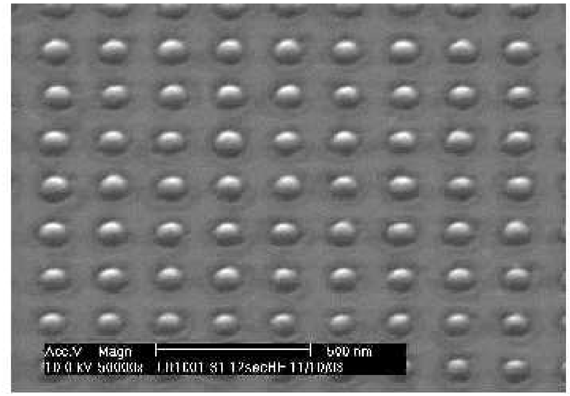
Spindt metal tips

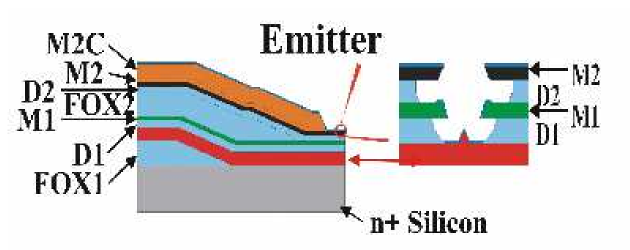


Nodular MIS emitters



NanoTEL emitters

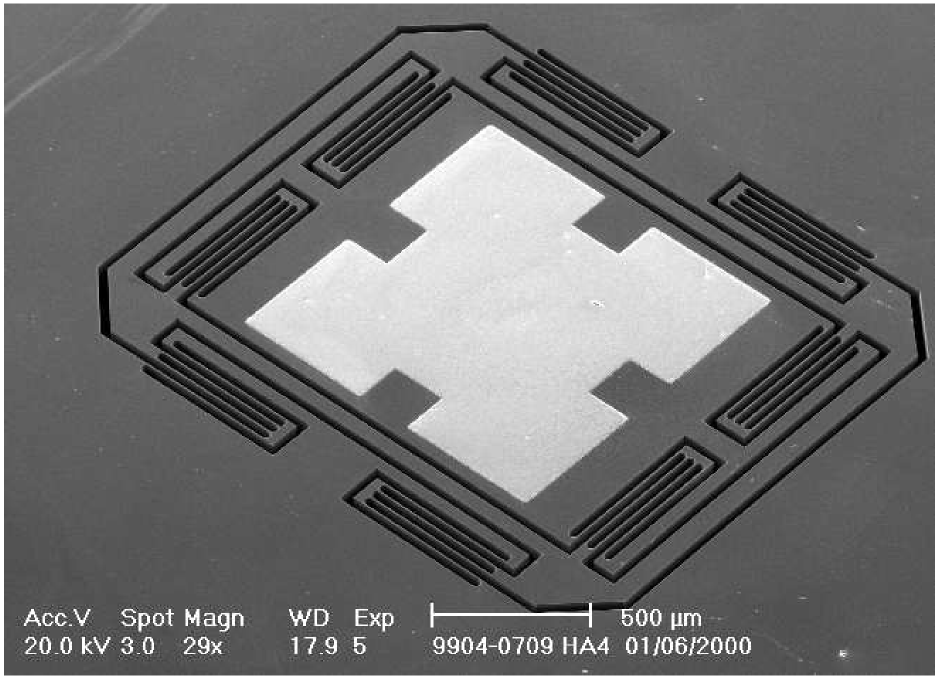


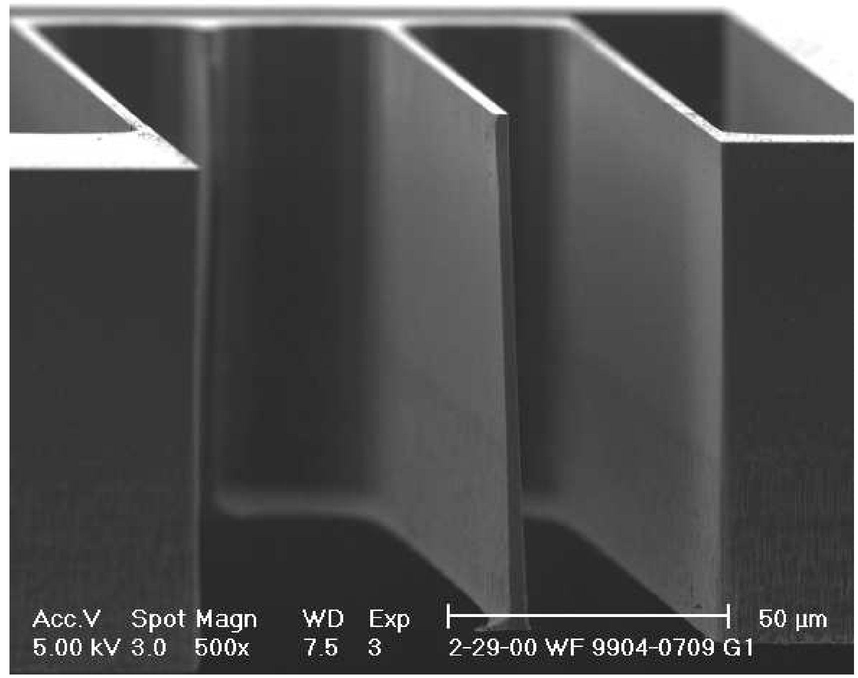


Considered 3 different kinds of emitters:

- 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

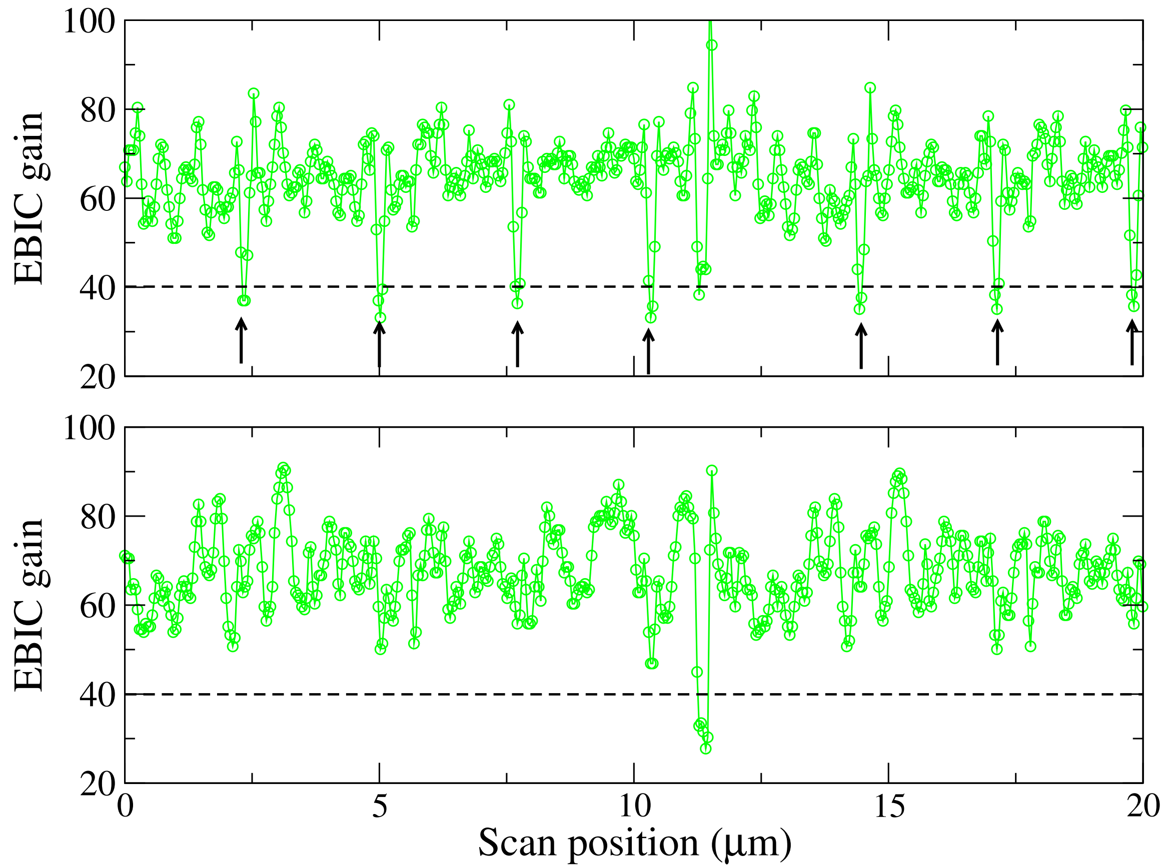




Features:

- 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.

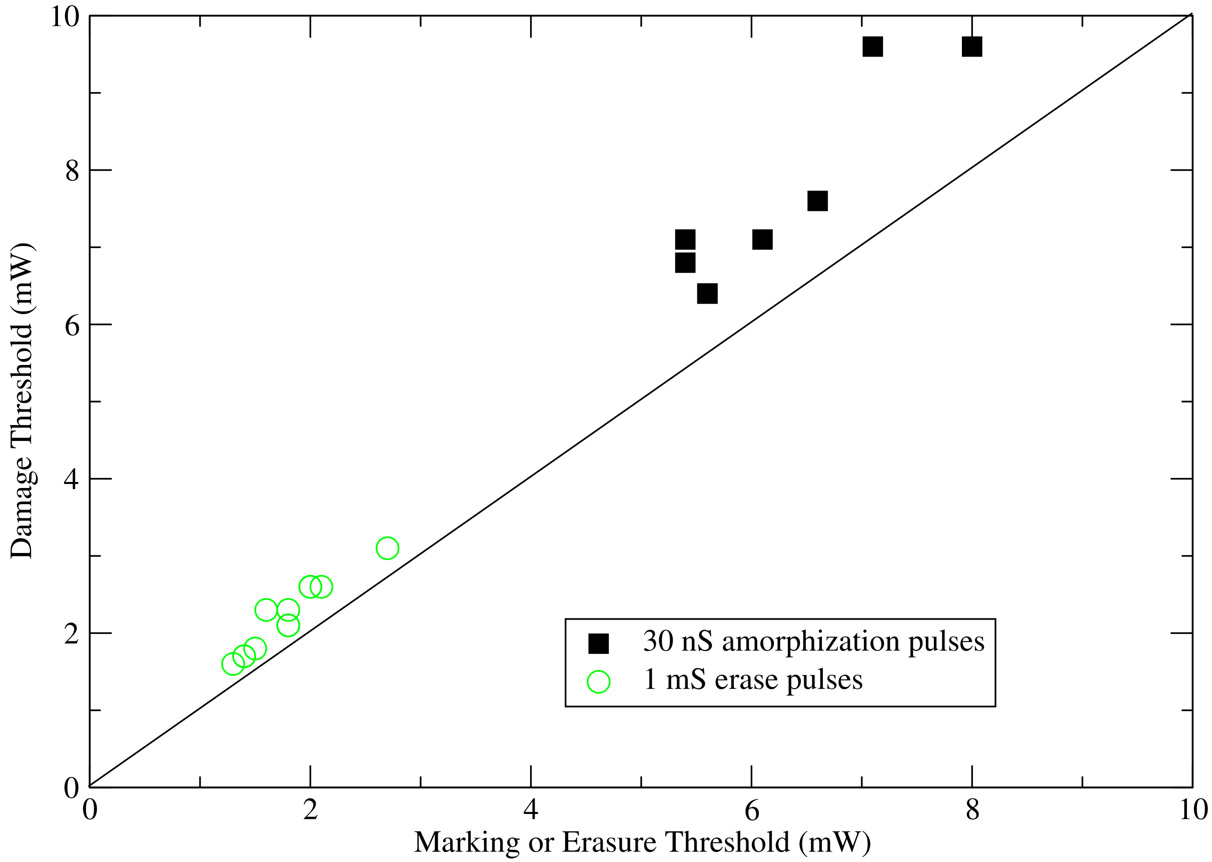
Oven Erasure of Amorphous Bits



Annealed at 300 °C for 5 minutes.

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

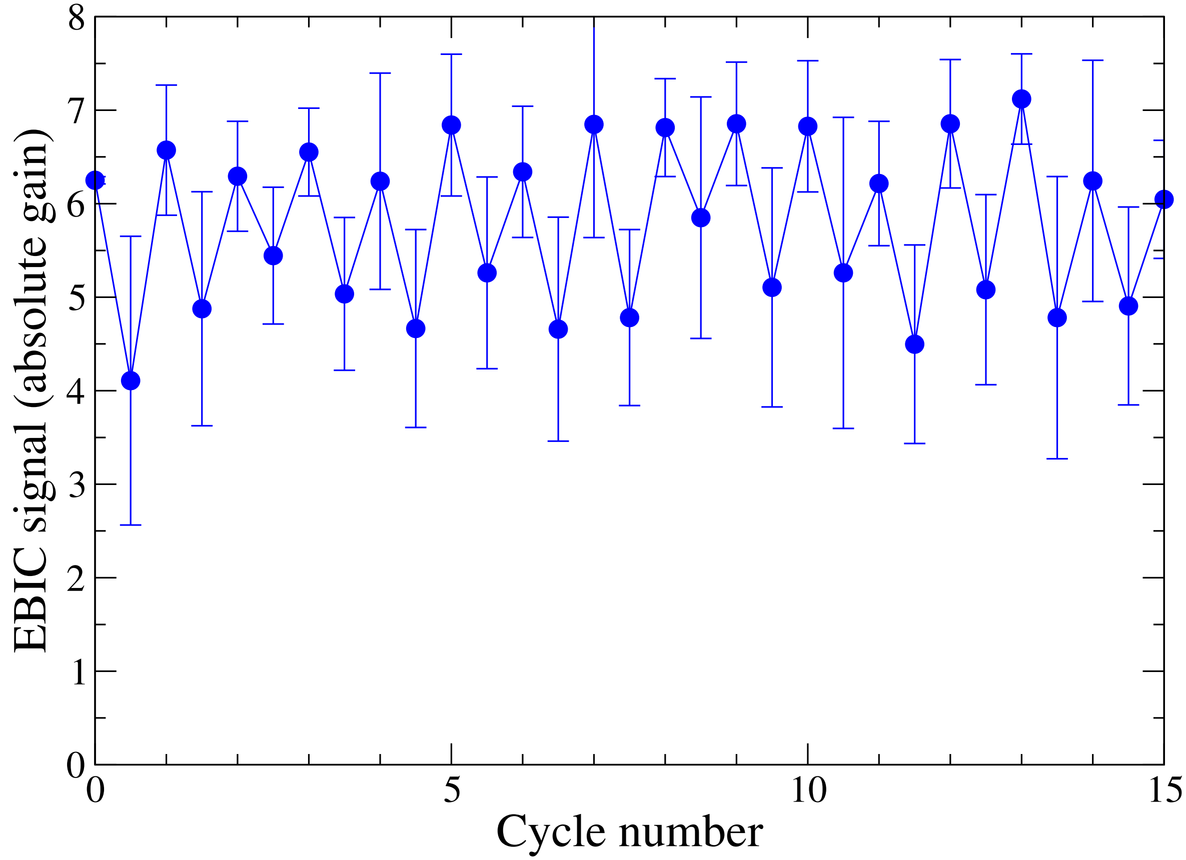
Margins for Write and Erase Processes are Small



Larger margins correspond to thicker cap layers.

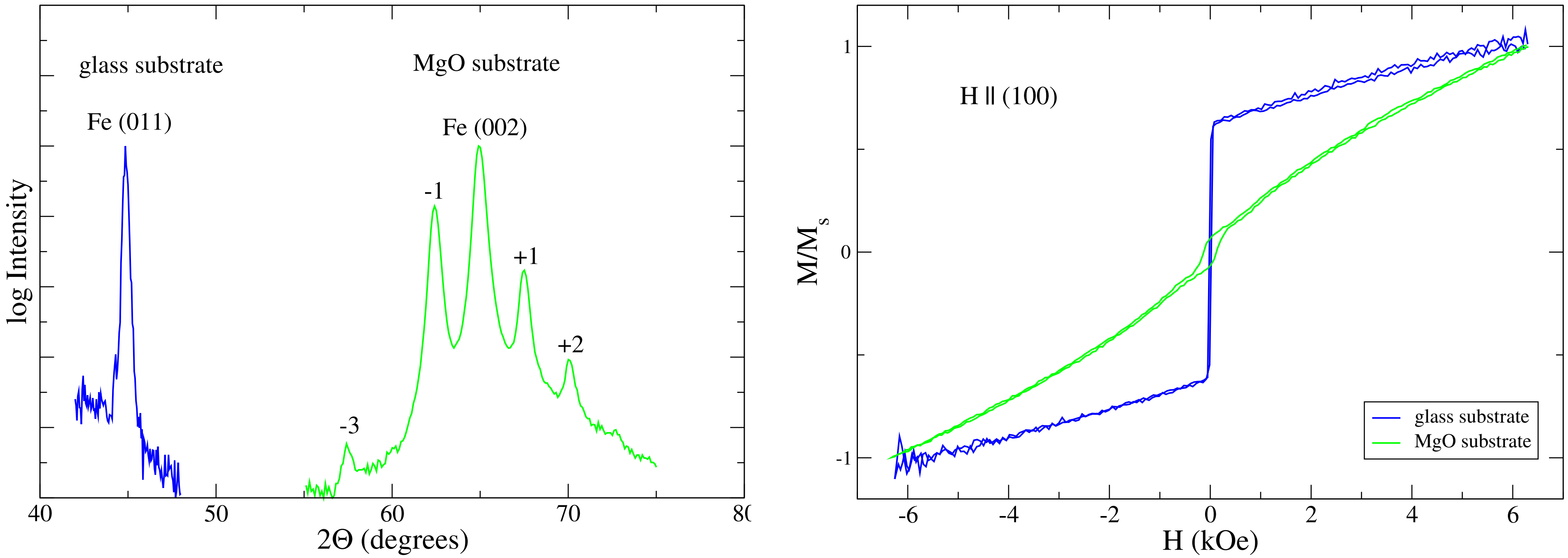
Best cycling behavior has not been demonstrated on films with best gains.

15 Cycles without Degradation Achieved



Needs contrast optimization via improved film growth, layer thicknesses, doping, cap layer, beam energy, device bias . . .

Diffusion-induced crystallization in epitaxial silicides



Made by ion-beam sputtering Fe and Si in a multilayer.

Metastable bcc FeSi grows on Fe.