Recording physics of scanned-probe storage media

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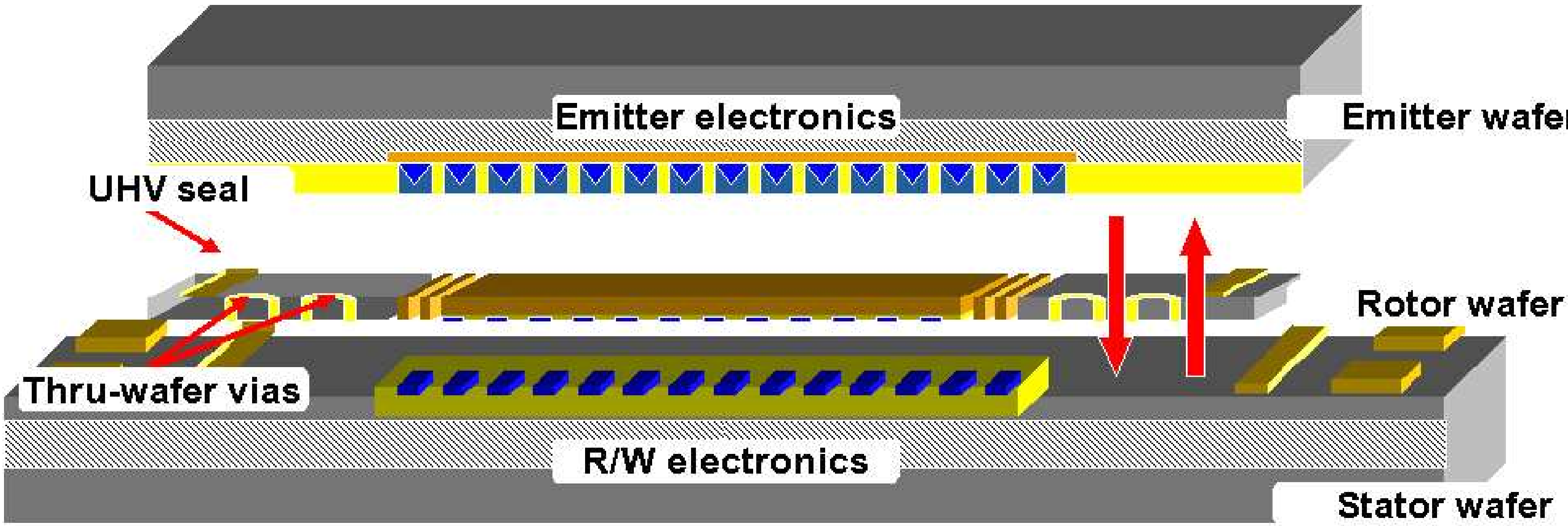
- Rationale for electron-beam scanned-probe data storage
- Media material requirements
- Reading, writing and erasing amorphous bits

hp invent

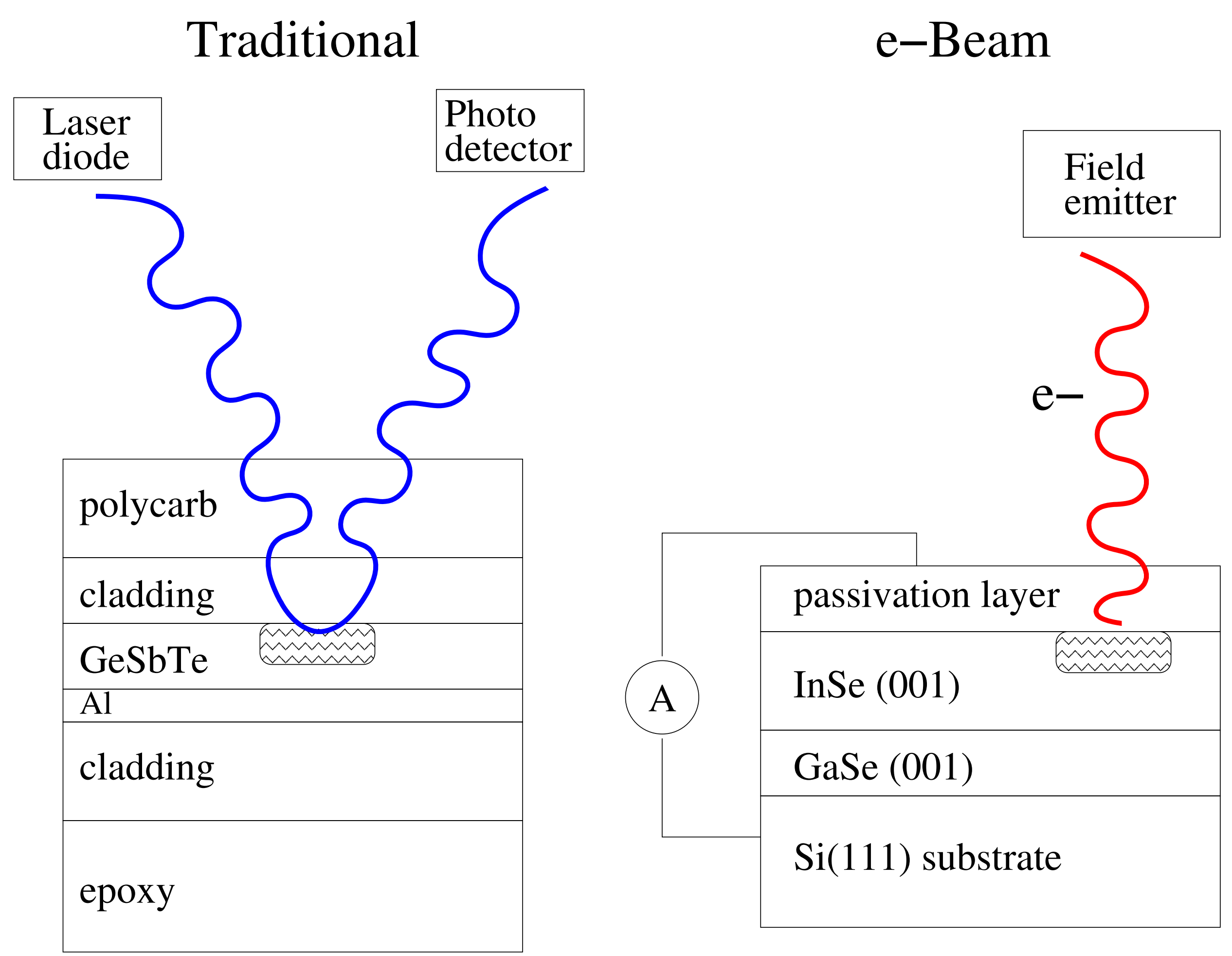
Electron-Beam Recording on Phase-Change Media



Features:

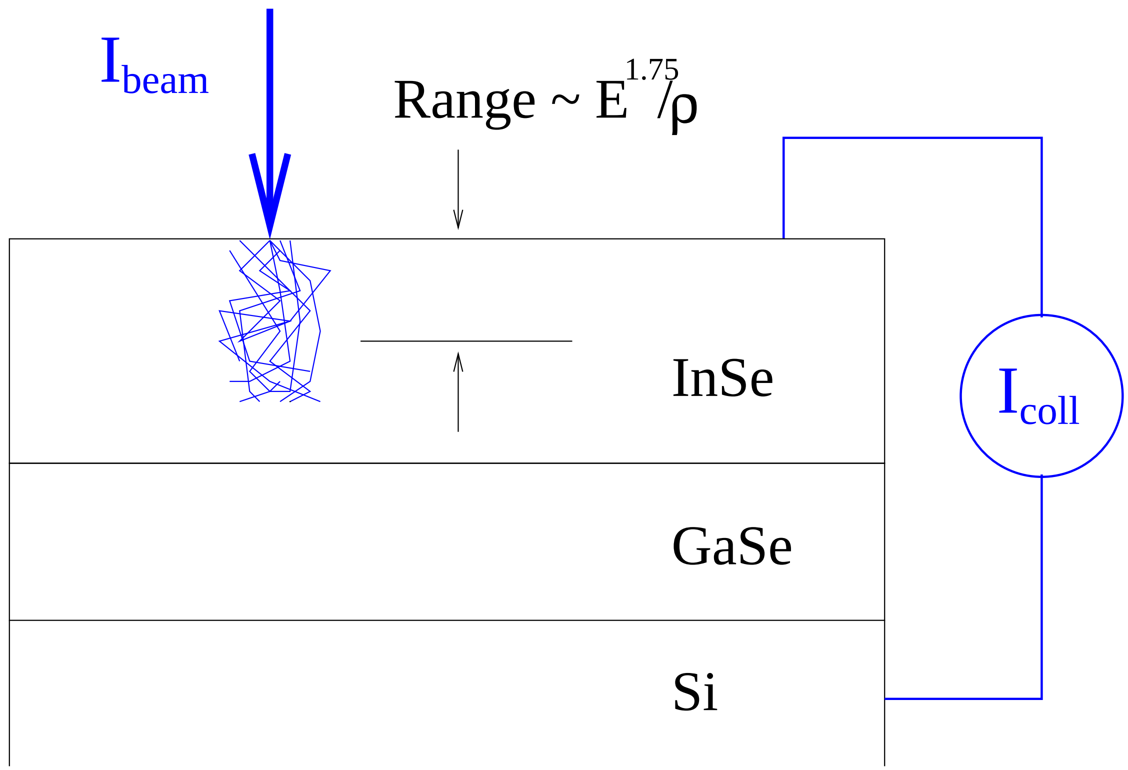
- Unpatterned media scanned in two dimensions;
- Reading and writing via electron-beam field emitters in vacuum;
- Phase-change media for data storage.

Optical vs. Electron-Beam Recording



With e-beam storage, the data layer is part of the sensor.

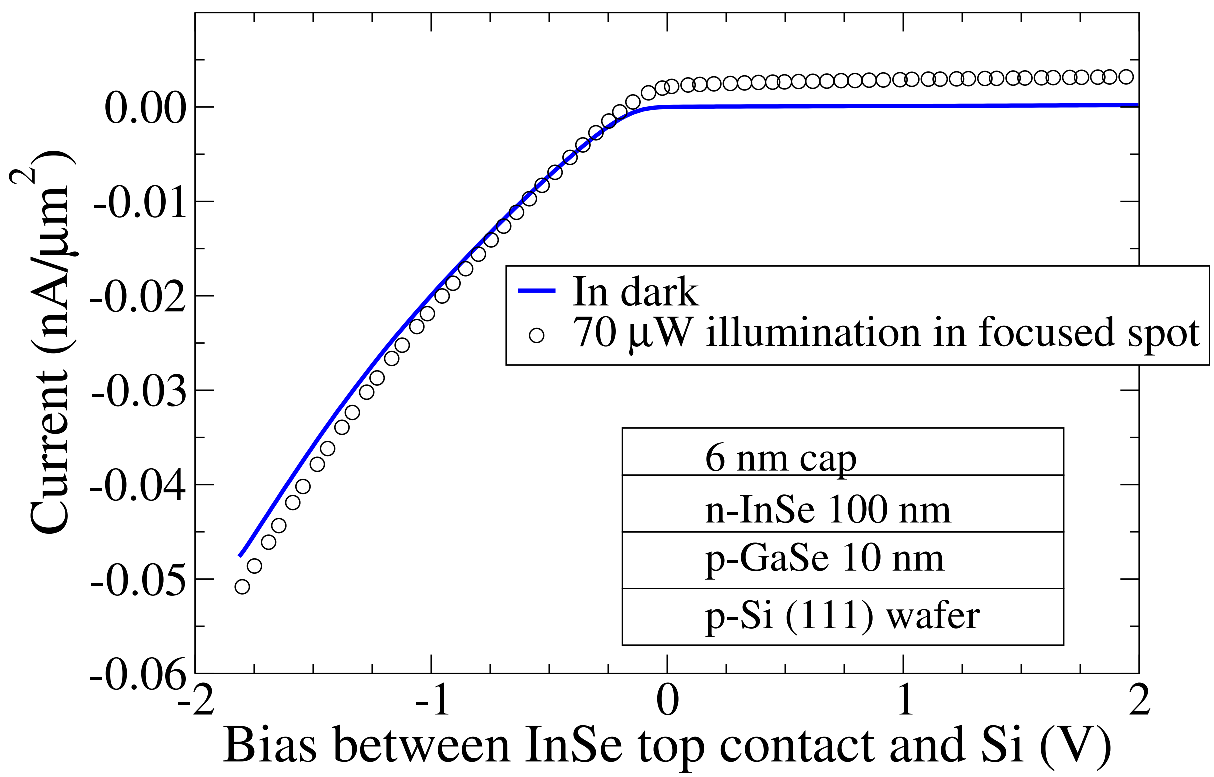
Electron-Beam Induced Current (EBIC) with keV Electrons Gives Gain



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

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

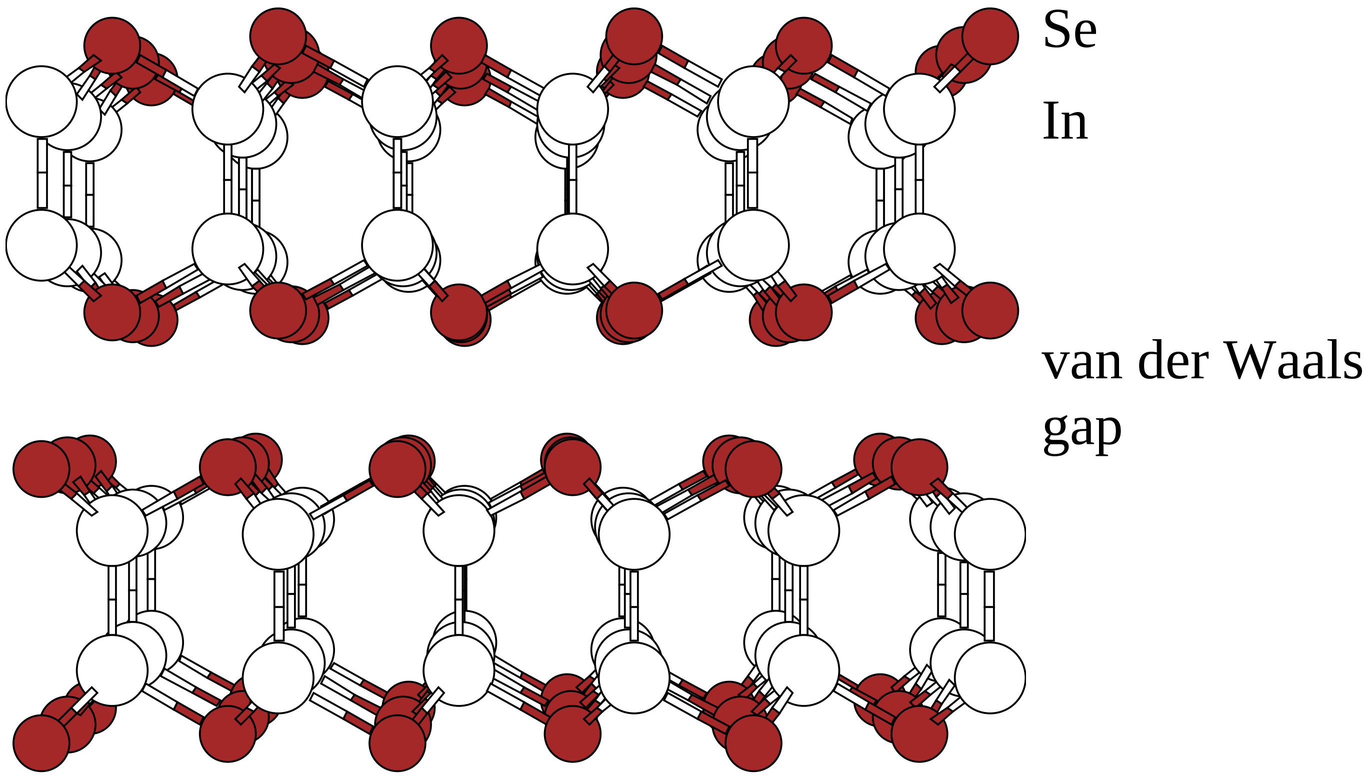
Decent Electrical Properties of InSe/GaSe Heterojunction Diodes



High crystallinity required for decent semiconductor properties.

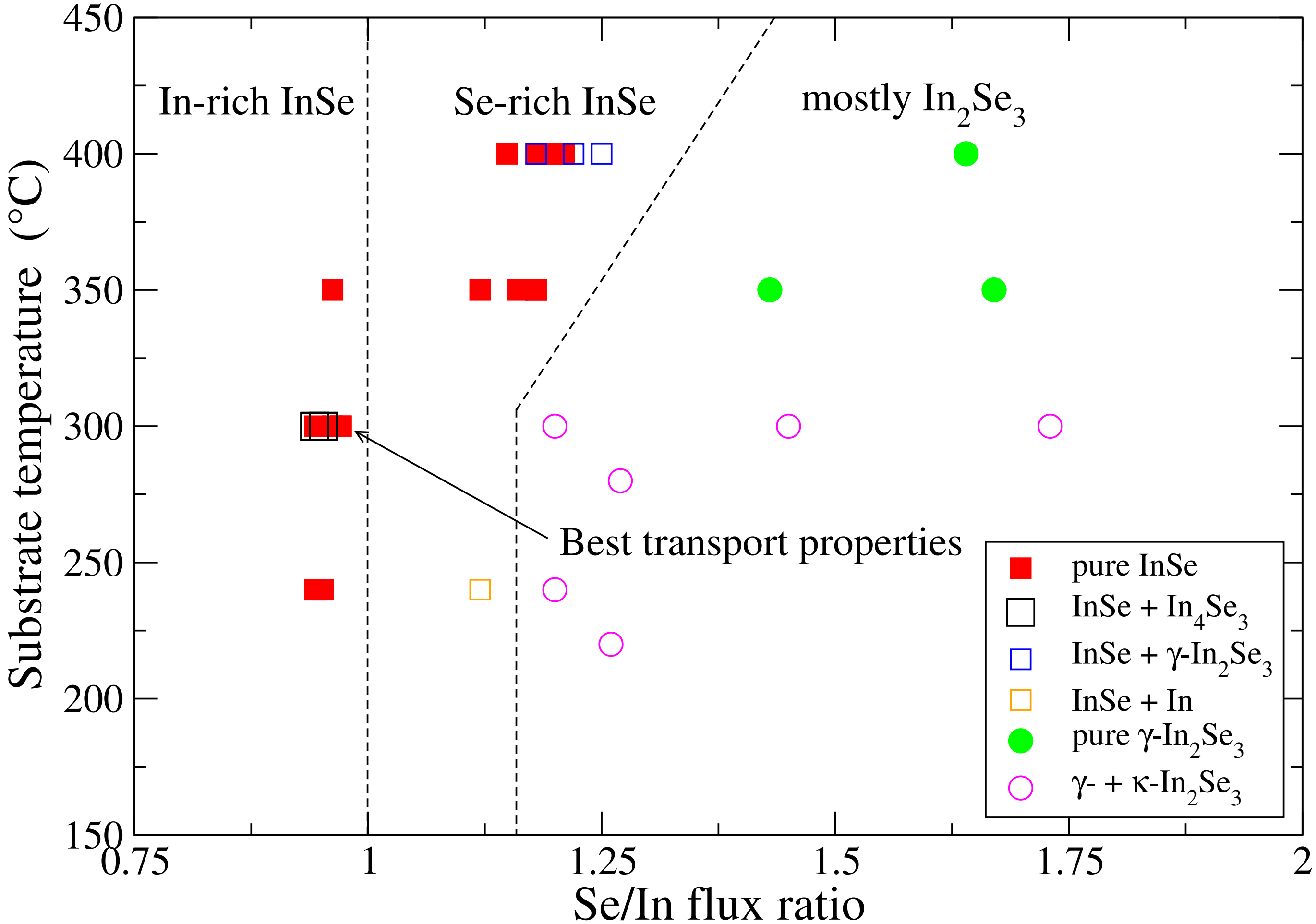
Measured collection efficiencies > 20%.

Crystal Structure of III-VI InSe and GaSe



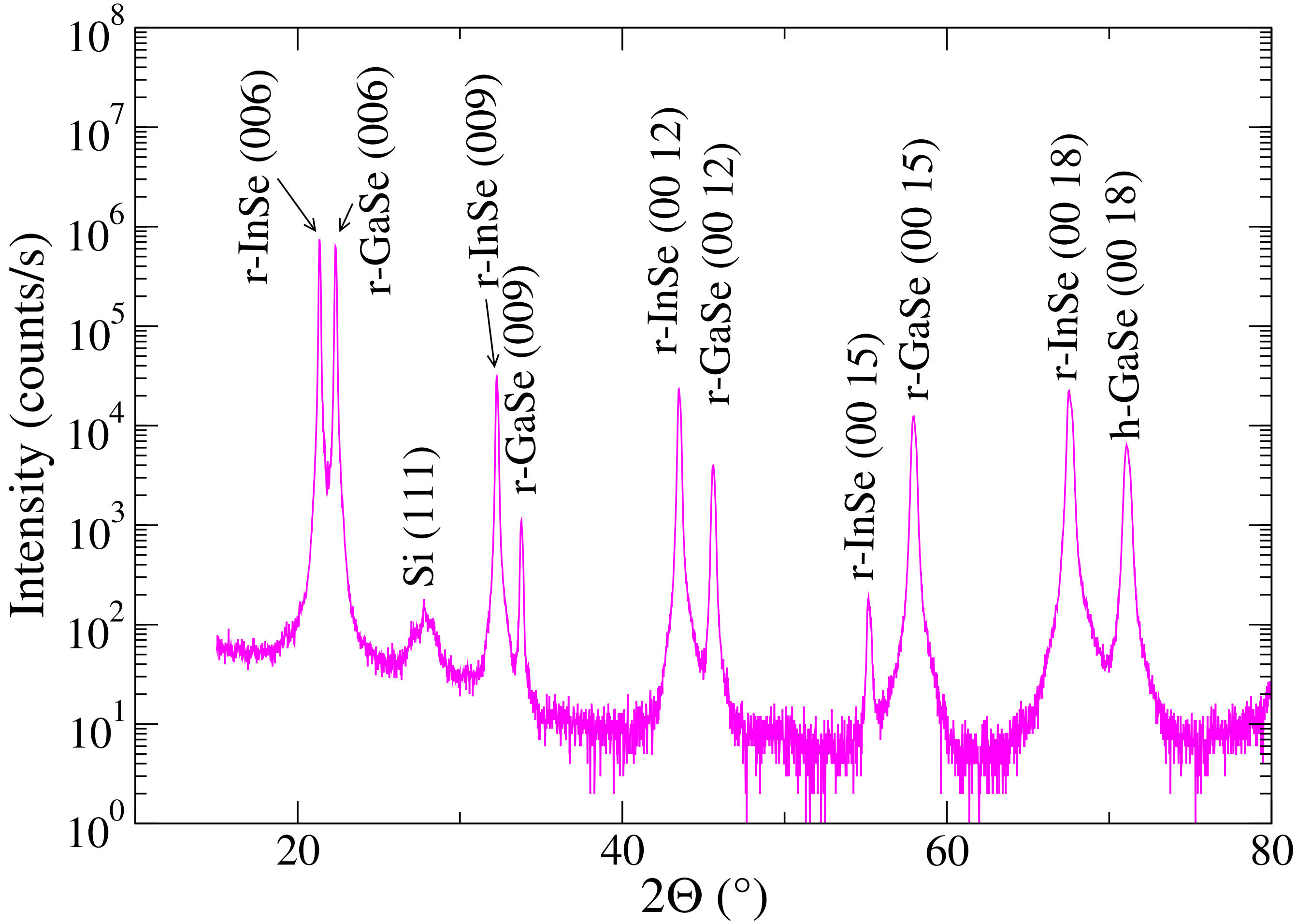
- GaSe grows epitaxially on Si(111) [Palmer *et al.*, JJAP 1993]
- InSe grows epitaxially on GaSe [Nakayama *et al.*, Surf. Sci. 1991]
- Substantial electrical and thermal anistropy in both materials.

MBE Growth Study of InSe Films



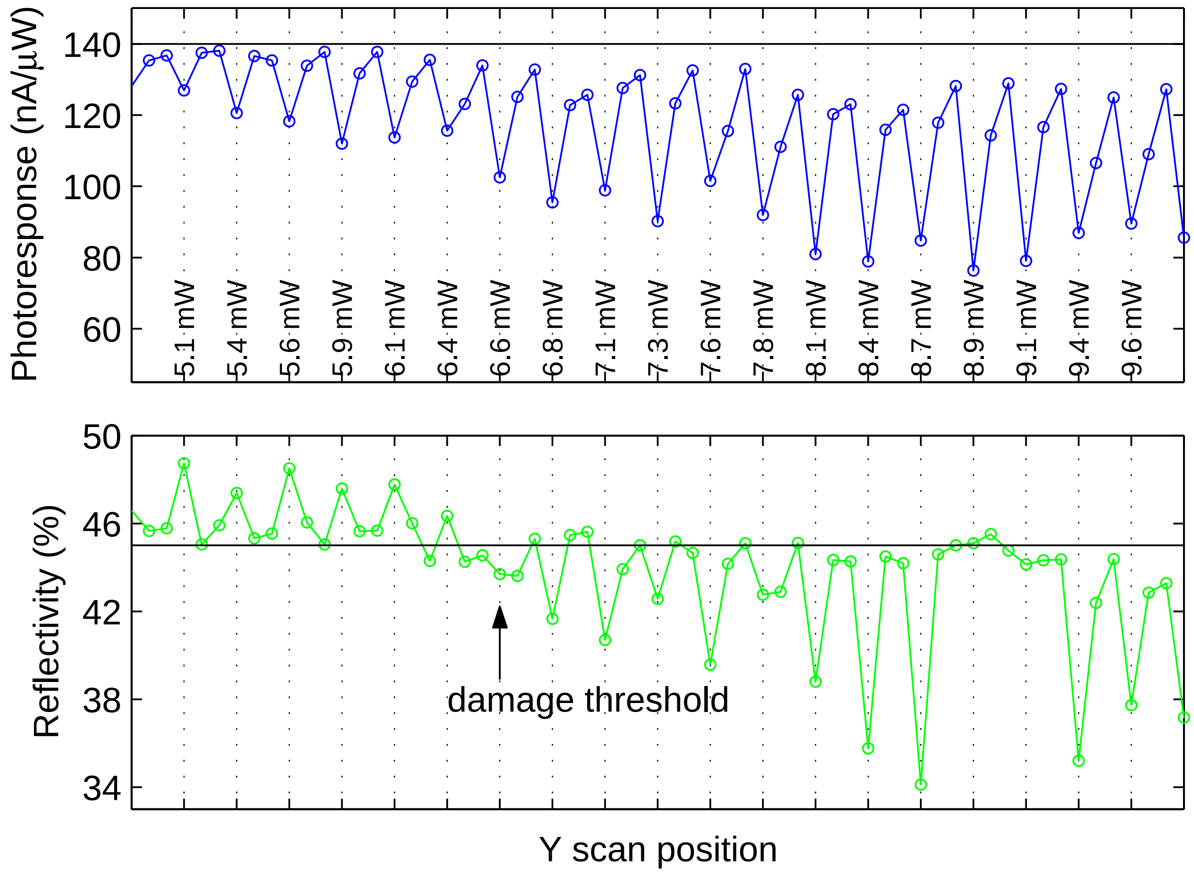
Phase purity as determined by x-ray diffraction.

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



Single-phase, well-oriented films with decent semiconducting properties that grow well on Si!

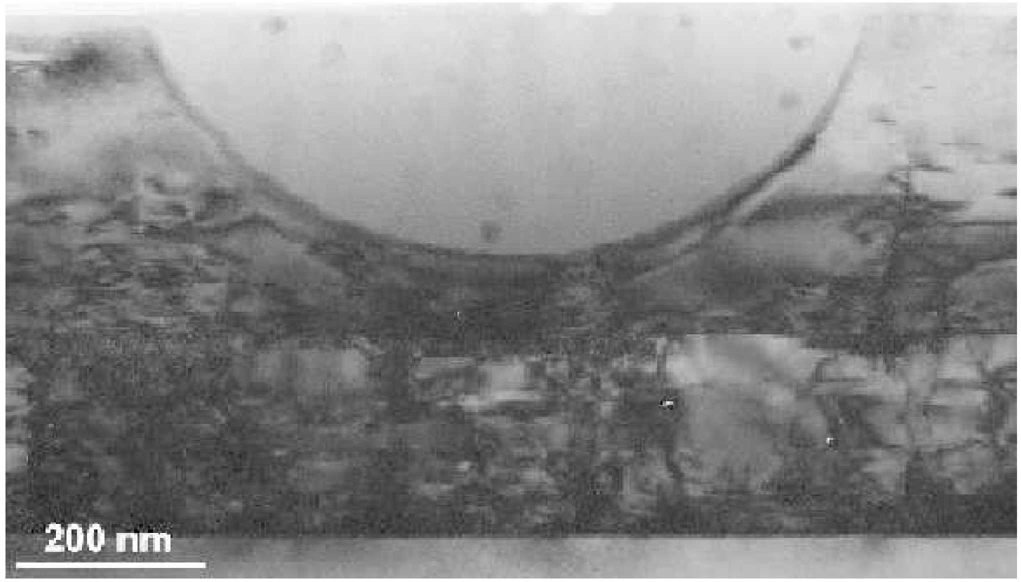
Write Parameters Optimized via Systematic Testing



Diffraction-limited, 30 nS 488 nm laser marks.

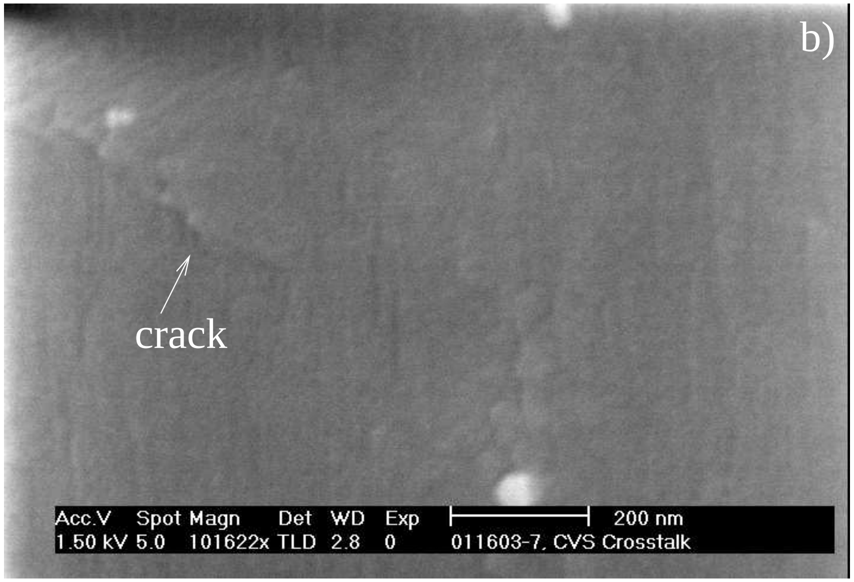
Reflectivity changes sign at damage threshold.

Laser Marked Regions are Amorphous

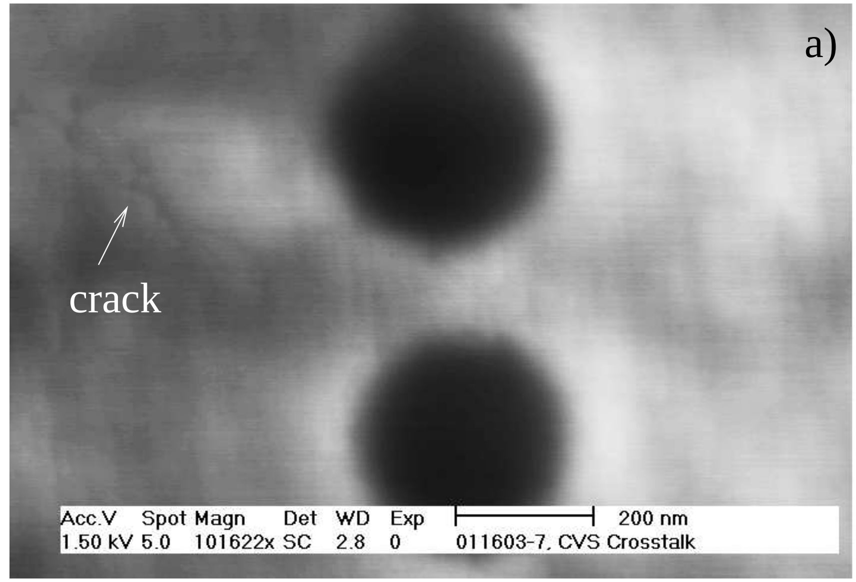


Short laser pulses used to simulate e-beam recording.

Electronic Contrast Observed without Damage



SEM Image

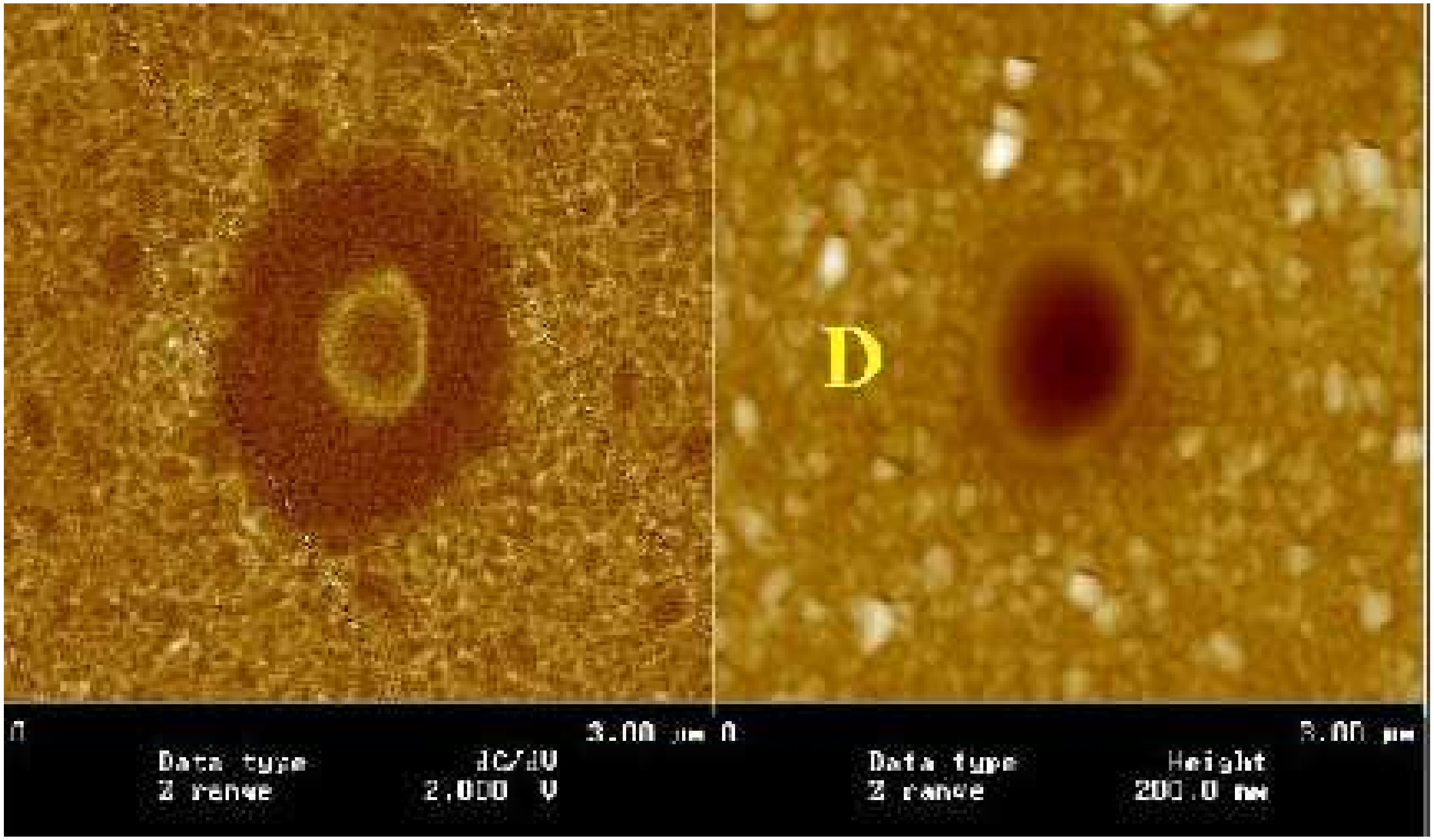


EBIC (collection efficiency) map

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

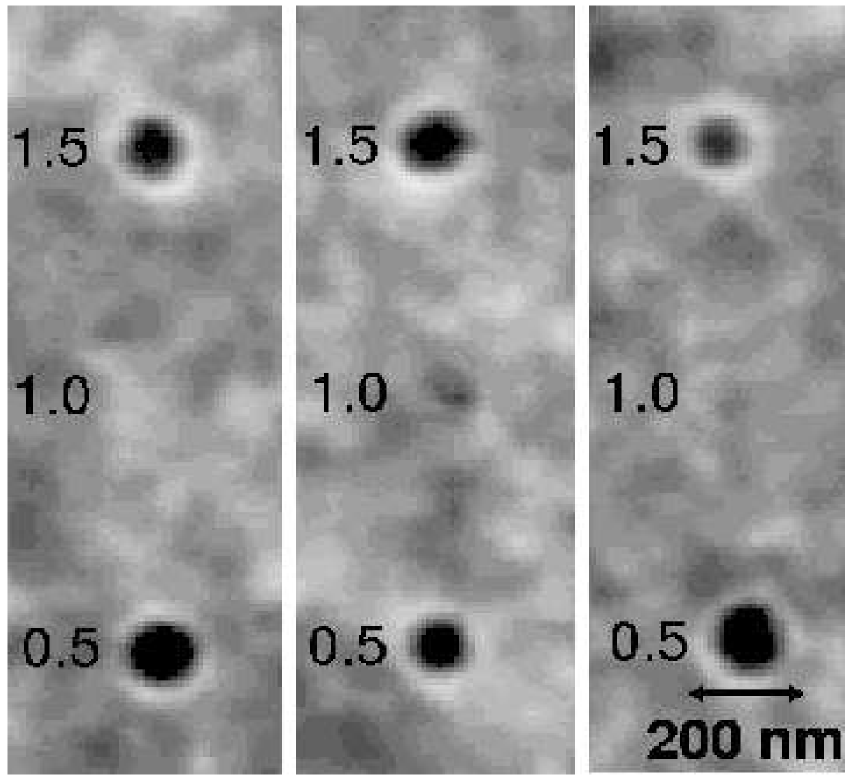


Scanned capacitance image　　　　Topographic image

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

Erasure without Surface Damage

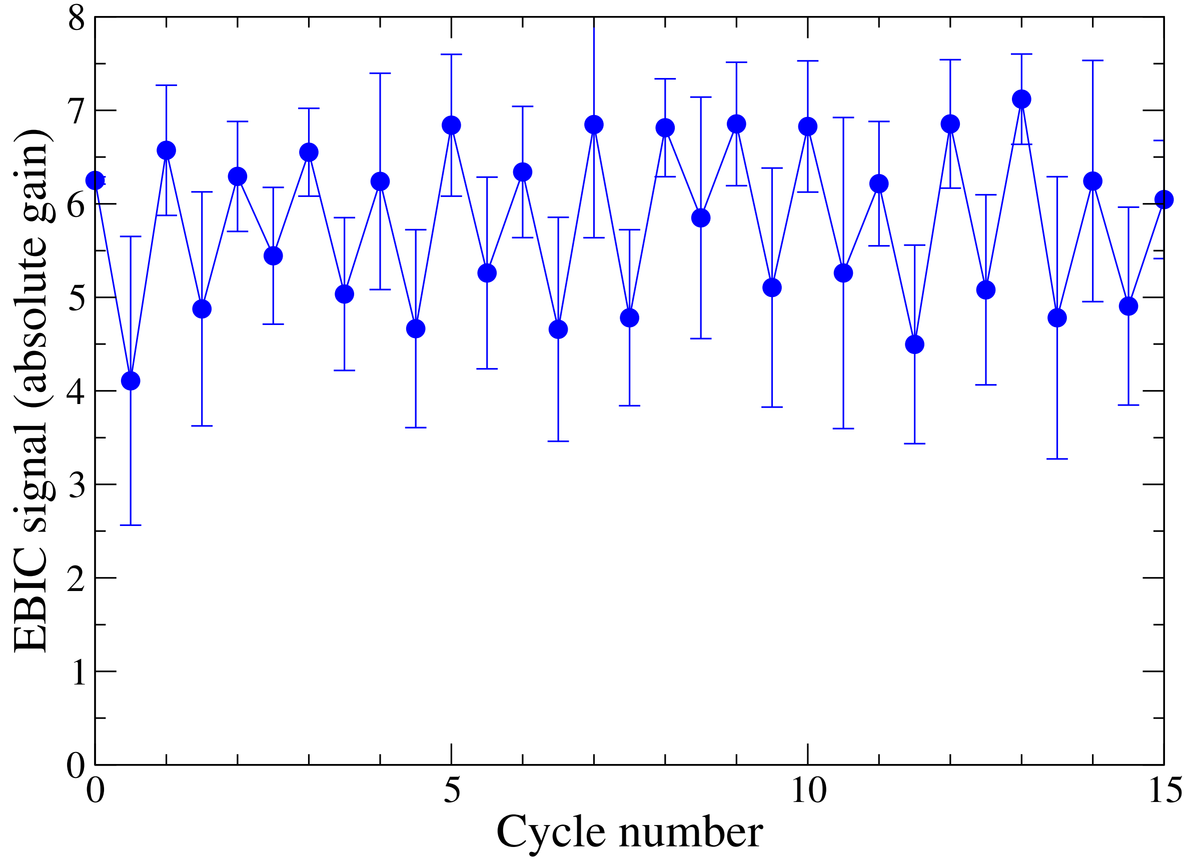
0.5 = Write pulse only; 1.0 = Write/Erase; 1.5 = WEW . . .



EBIC (collection efficiency map) images

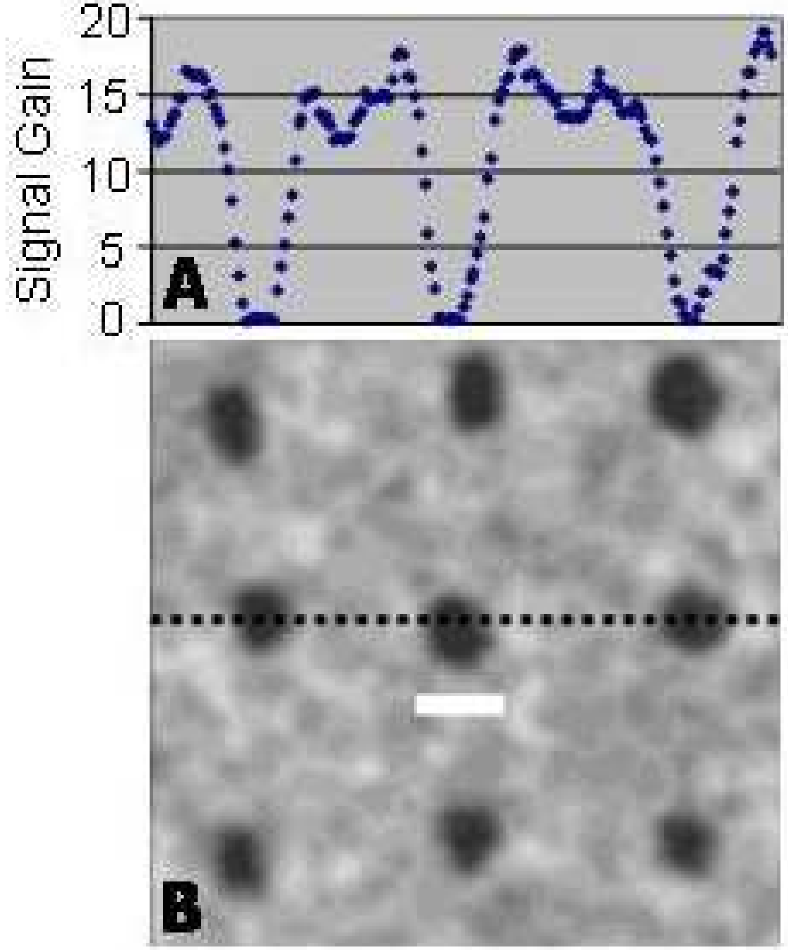
Up to 100 cycles with only minor degradation.

15 Cycles without Degradation Achieved



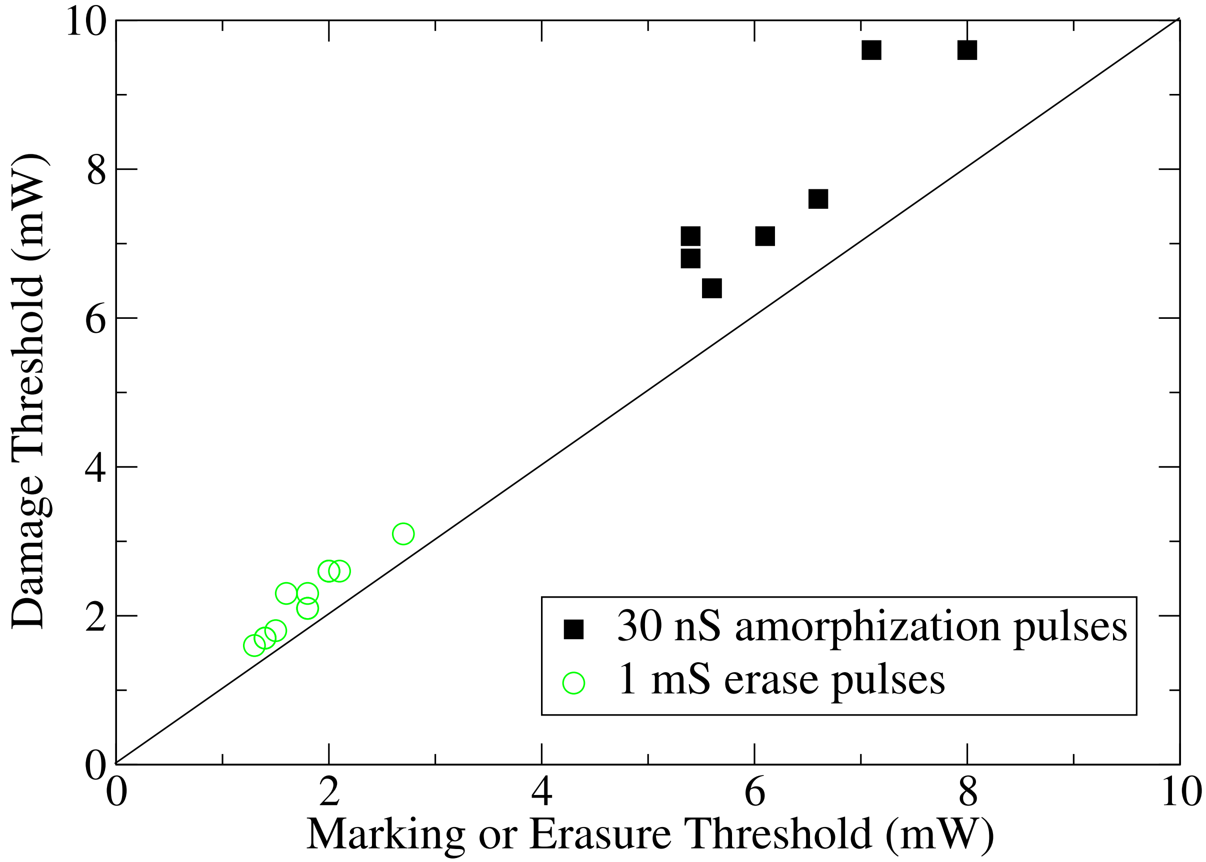
Biggest challenge: no electron-transparent overcoat layer exists.

Engineering tradeoffs in media development



Thinner media with thinner overcoat shows better contrast but is harder to erase.

Margins for Write and Erase Processes are Small



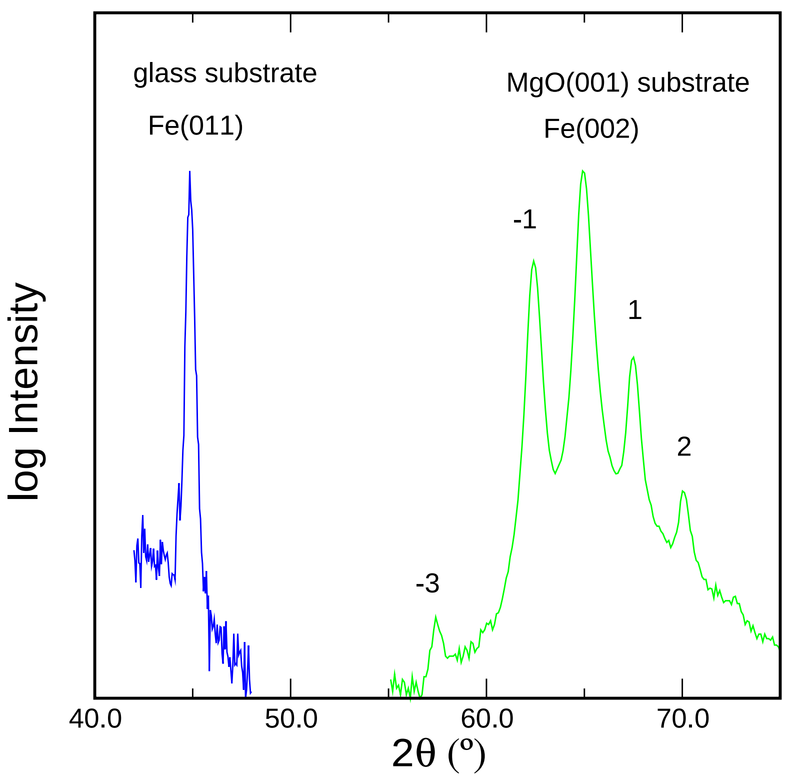
Larger margins correspond to thicker overcoat layers.

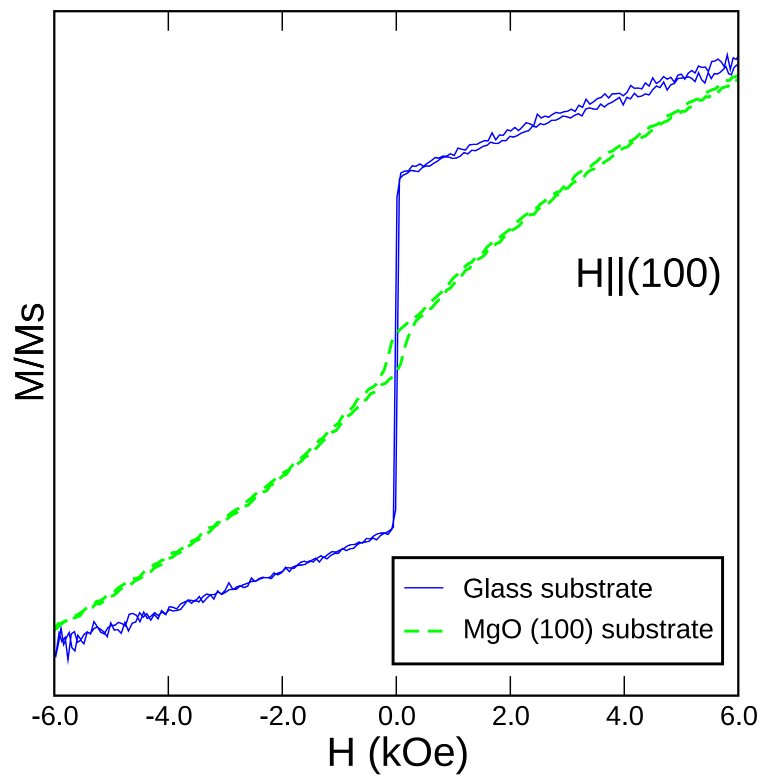
Best cycling behavior has not been demonstrated on films with best bit contrast.

Summary

- High-quality phase-change media films have been grown on Si(111).
- The III-VI semiconductor phase-change media supports electron-beam recording with reasonable contrast.
- Erasure has been demonstrated with some contrast loss out to 100 cycles.
- Best write and erase parameters were found via automated, systematic variation of parameters.
- Media noise reduction and overcoat layer optimization remain major challenges.
- Previous work was on exchange bias, AF-coupled ML, GMR, magnetic film growth ...

Before scanned-probe, 8 years of magnetics work

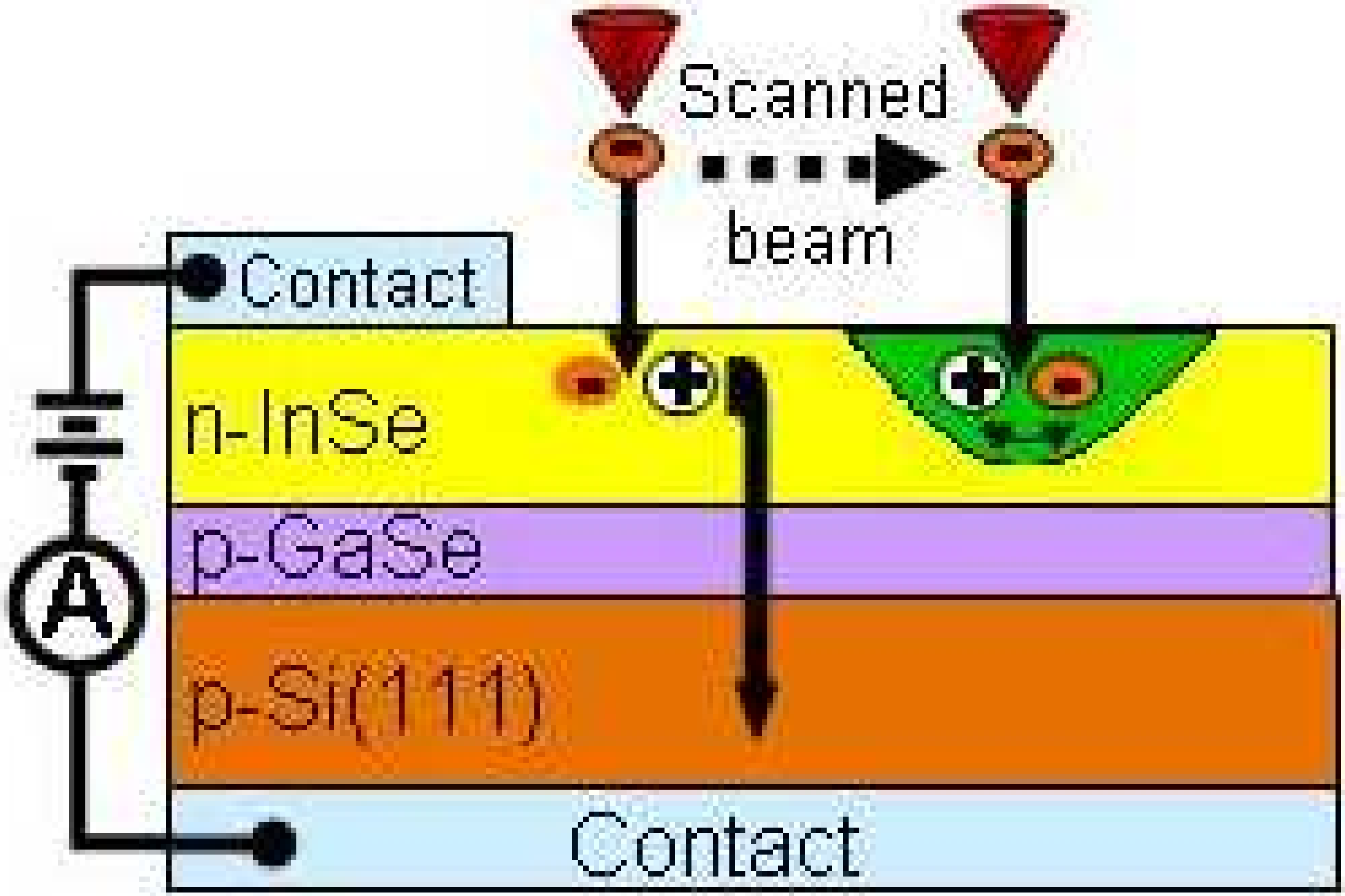




Epitaxial Fe/Si ML have stronger AF coupling.

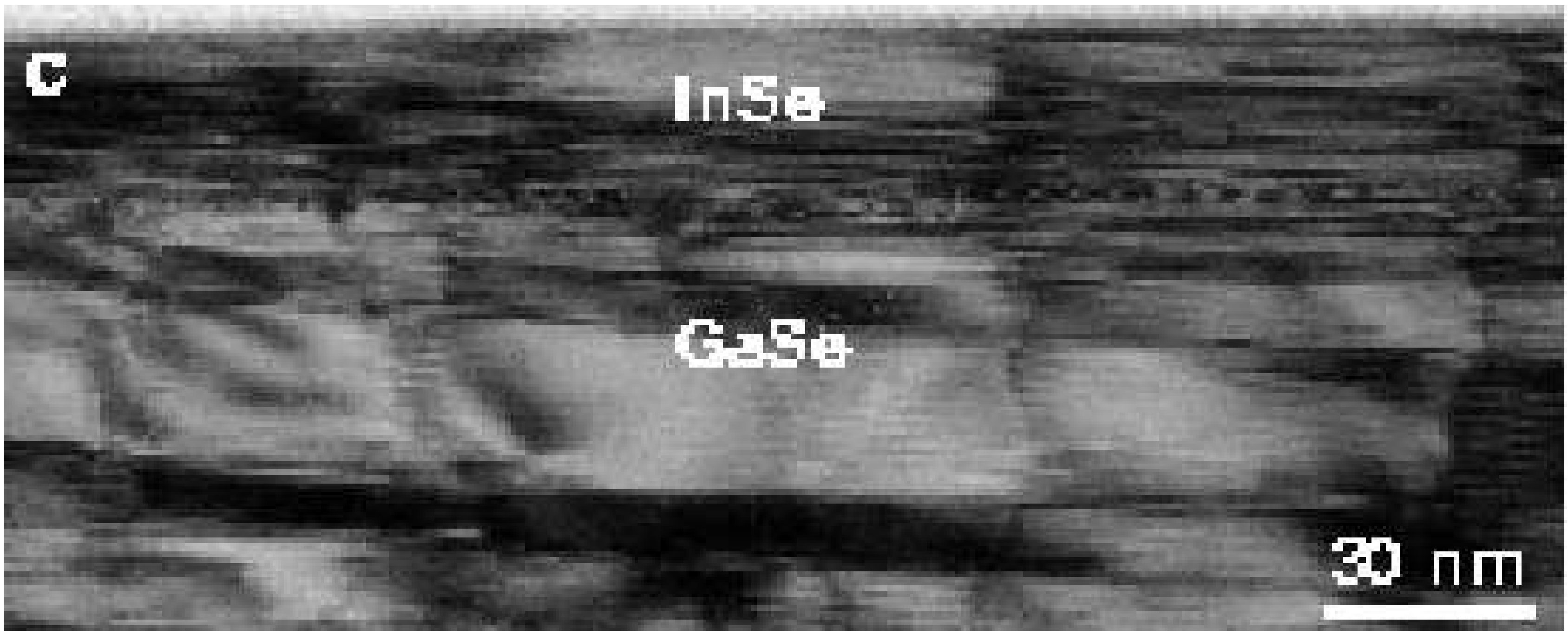
Collaboration with Rick Michel at LLNL, 1994-1996.

Data Readback Concept



InSe/GaSe Films are Defect-Tolerant like GaN

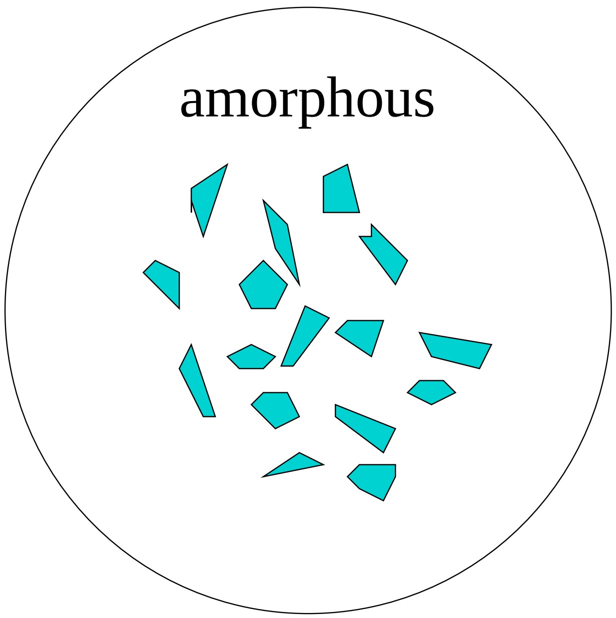
Films have twins, stacking faults and threading dislocations.



Highly defected films have reasonable device performance.

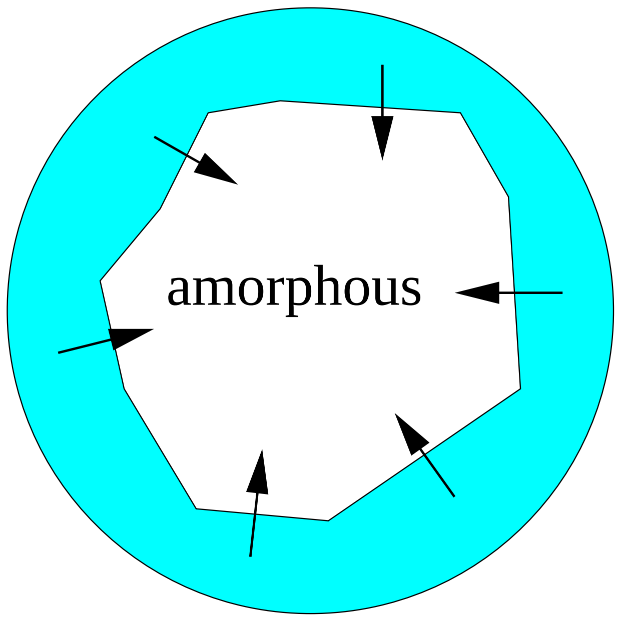
Scaling of Erasure Time Depends on Recrystallization Mode

Homogeneous nucleation plus growth



Like GeSbTe

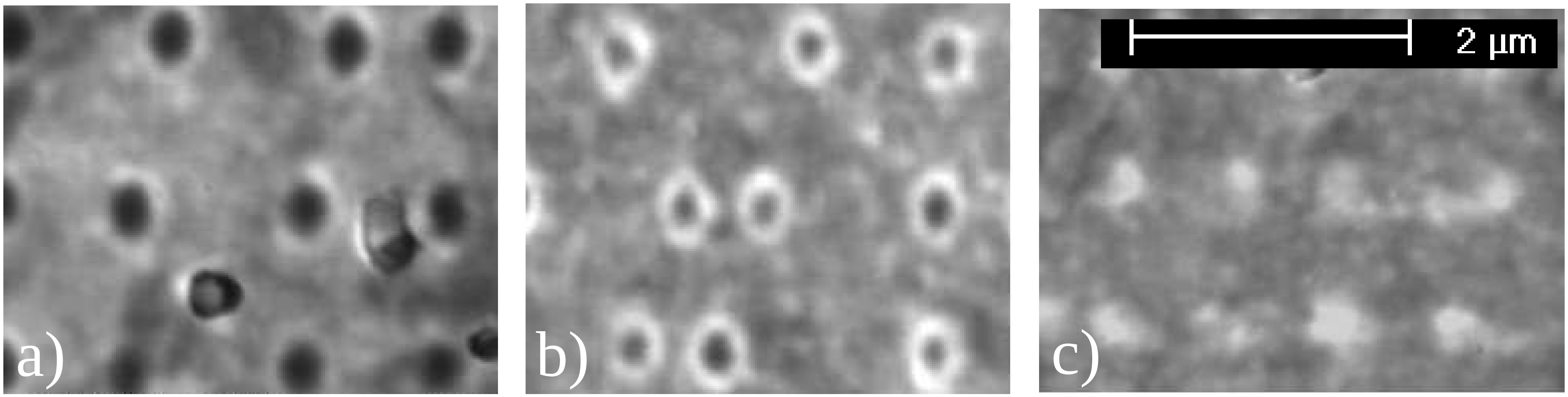
Regrowth from crystalline matrix without nucleation



Like InAgSbTe

Some Evidence for Regrowth from the Matrix

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

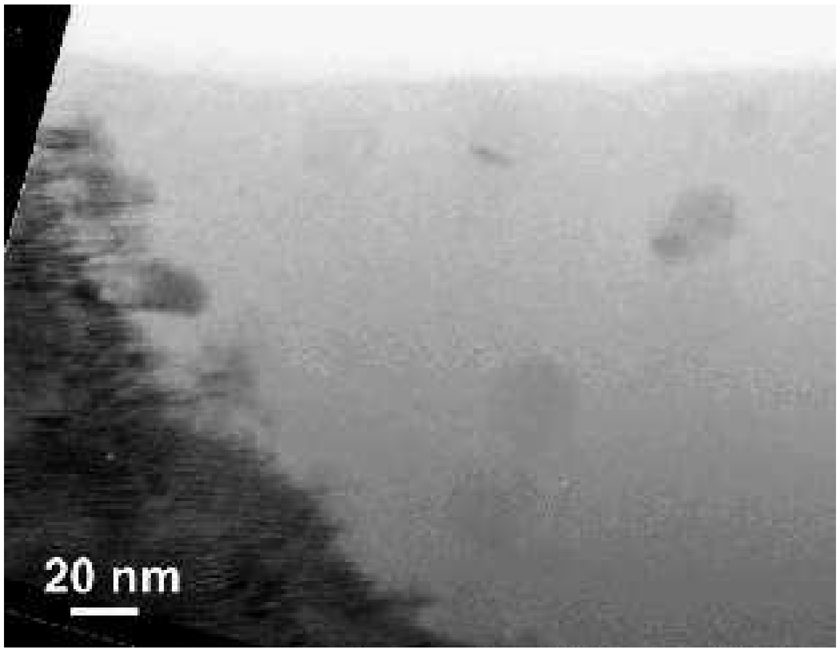


EBIC (collection efficiency map) images

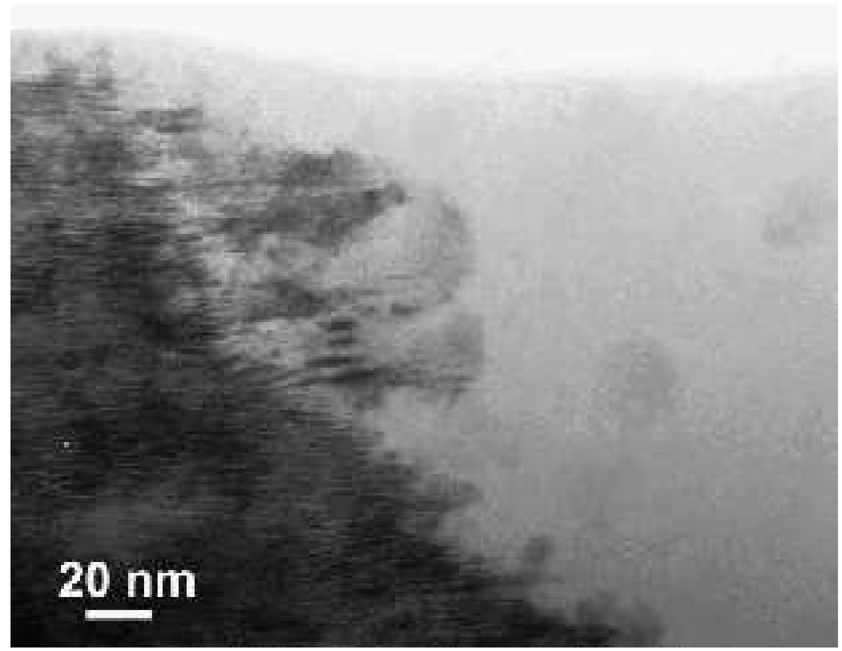
As erase pulse lengthens, bright ring grows inward.

Final erased mark has larger signal than surrounding matrix.

In Situ TEM Recrystallization Occurs from Mark Edge



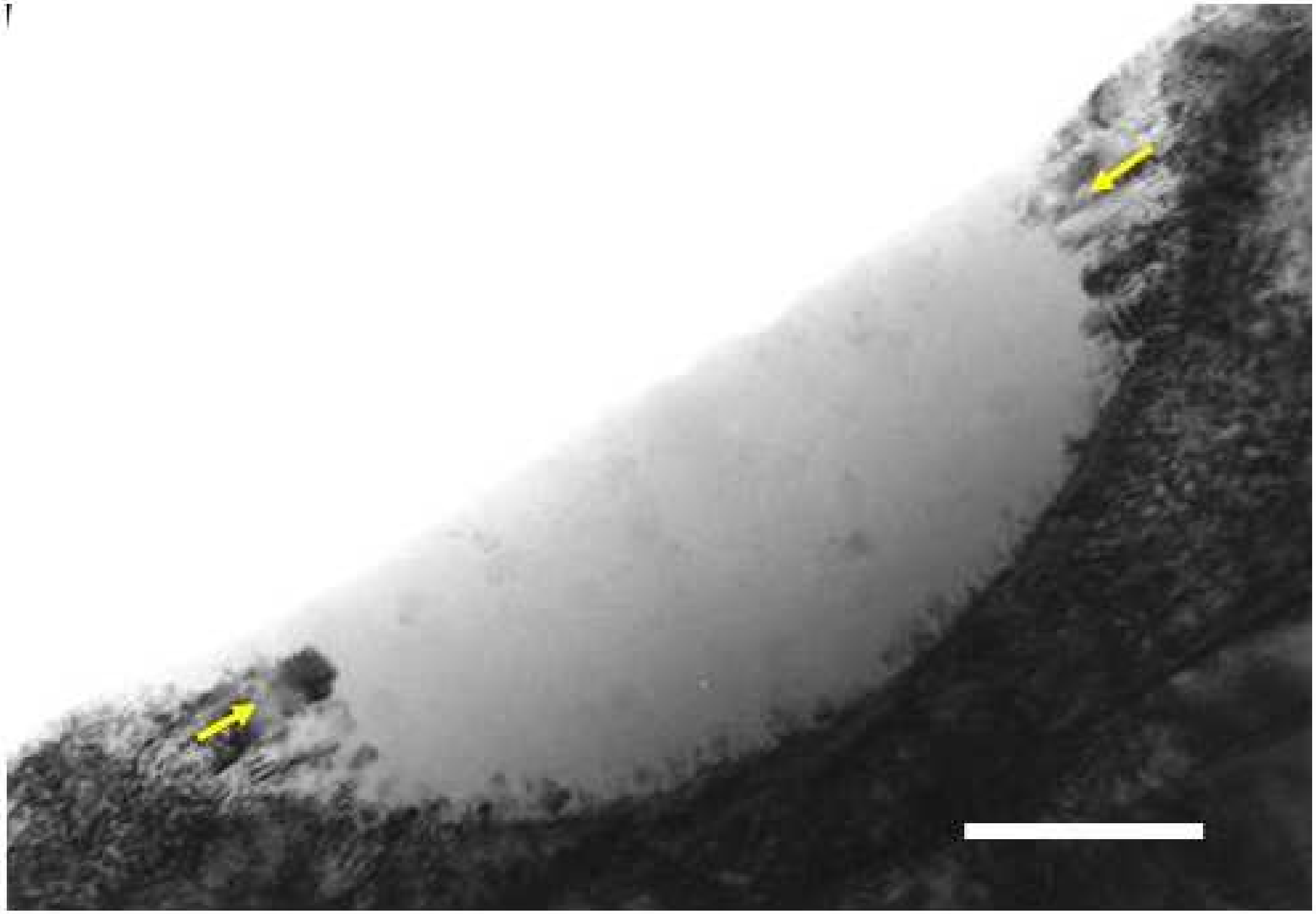
Write pulse only



Write + 1 S irradiation

Growth-dominant behavior can occur under some circumstances.

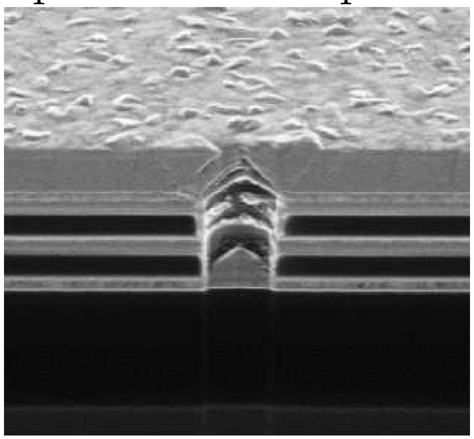
Larger View of E-beam Recrystallization at Edges



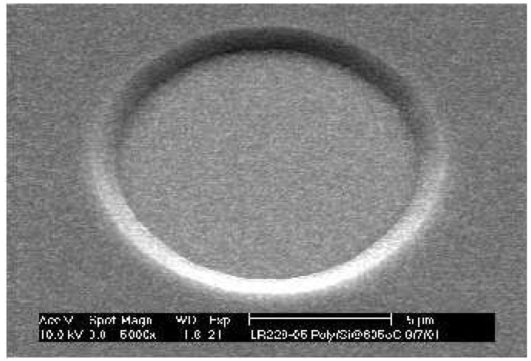
Diameter of bit at surface is about 800 nm (much larger than erasable bits).

Electron-Beam Emitters for Read/Write

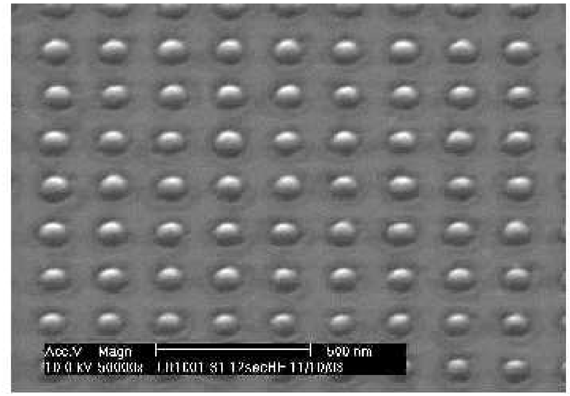
Spindt metal tips

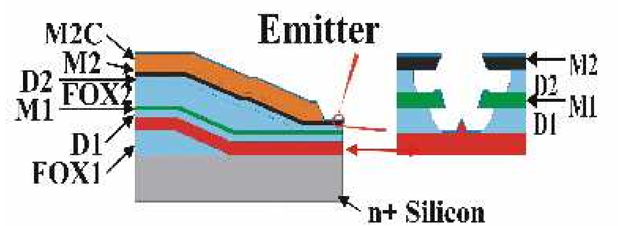


Nodular MIS emitters



NanoTEL emitters

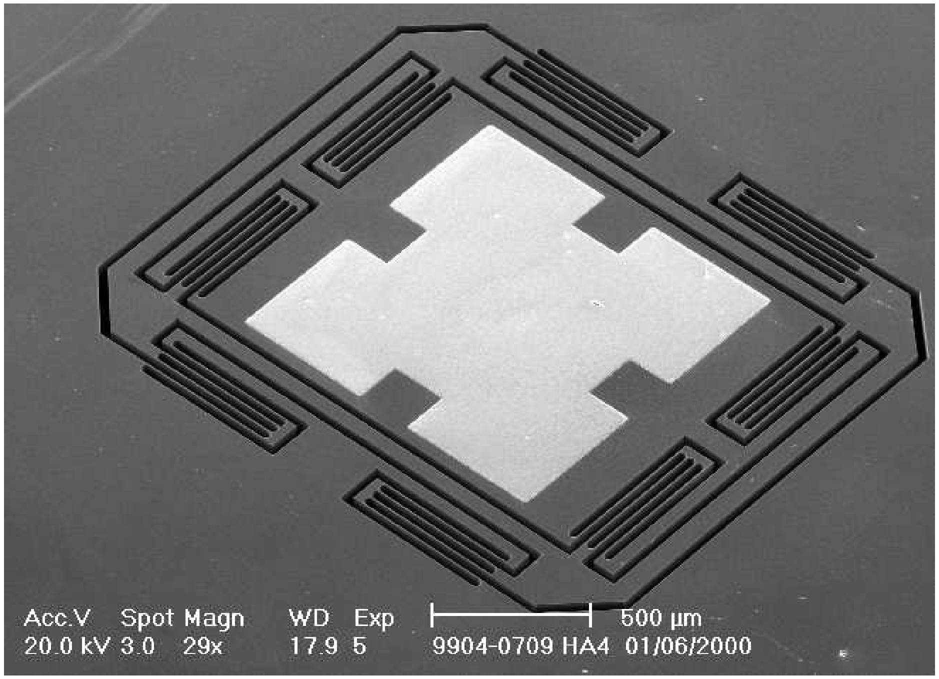


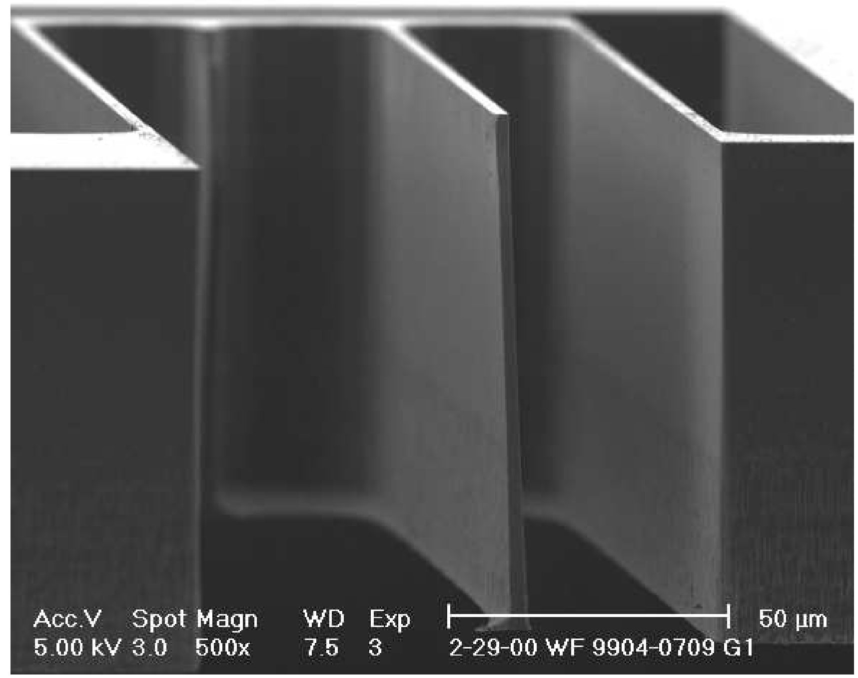


Considered 3 different kinds of emitters:

- 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

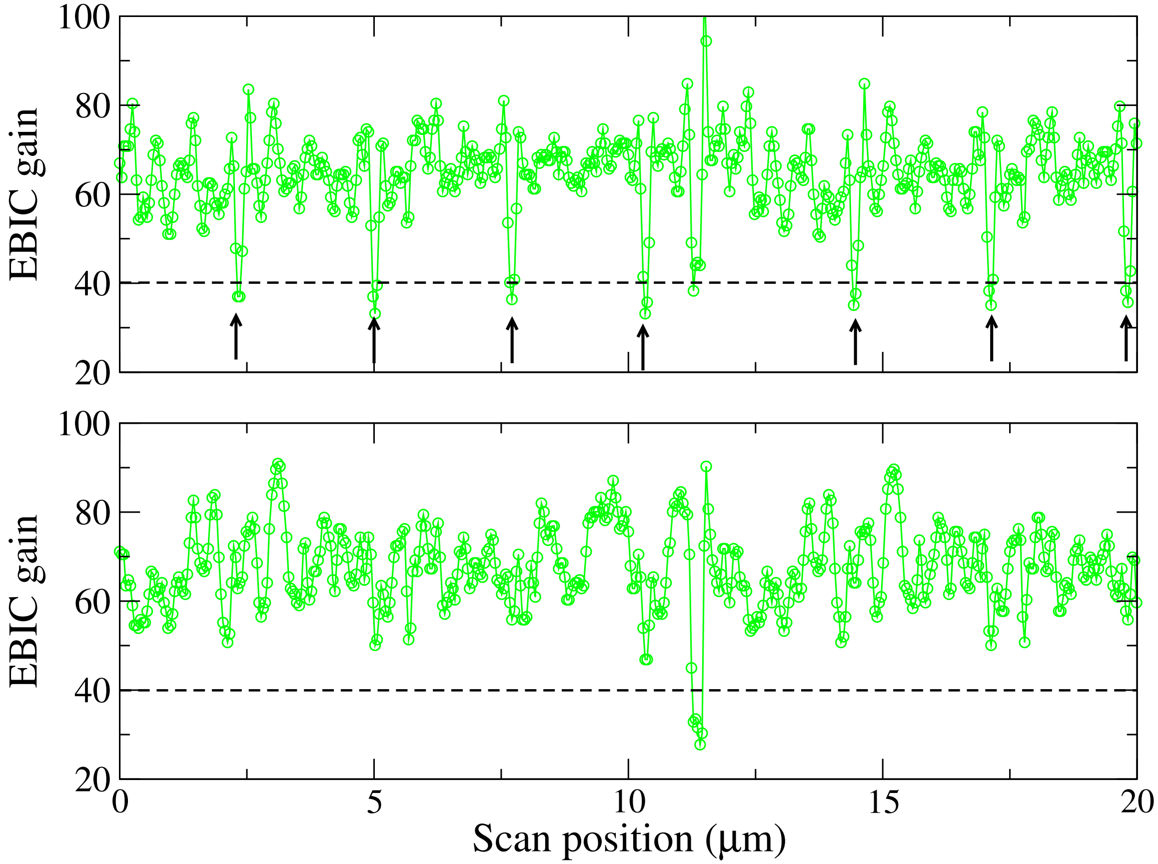




Features:

- 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.

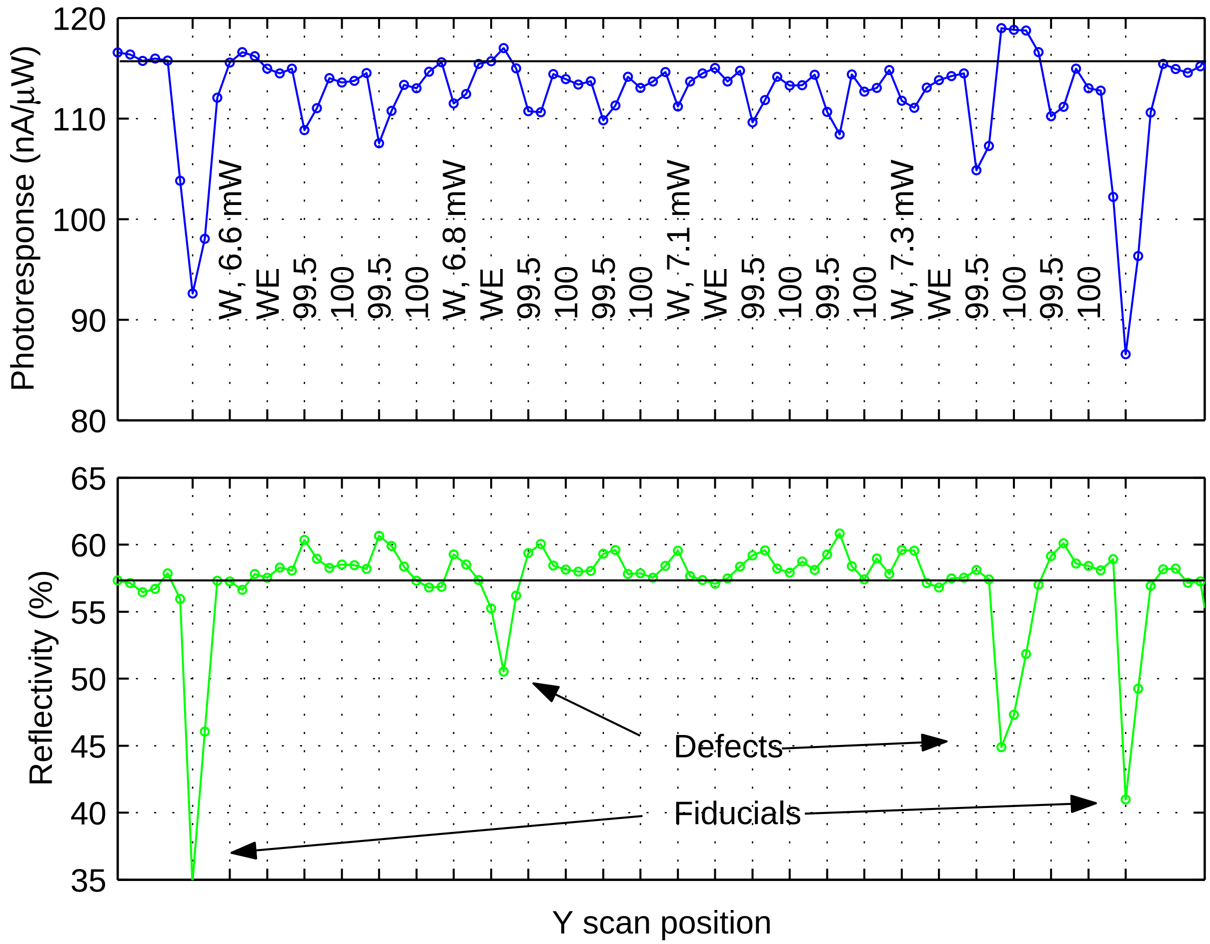
Oven Erasure of Amorphous Bits



Annealed at 300 °C for 5 minutes.

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

Erasure with some contrast loss to 100 cycles



Marks grow larger and fail to erase at the surface at 100 cycles.