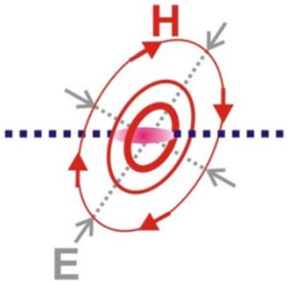
Material Studies with Compressed Electron & Positron Beams

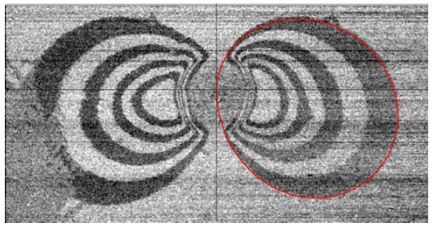
Ioan Tudosa

Outline

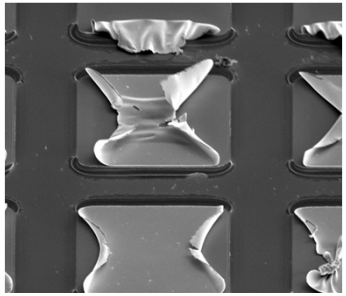
- EM field of Facet



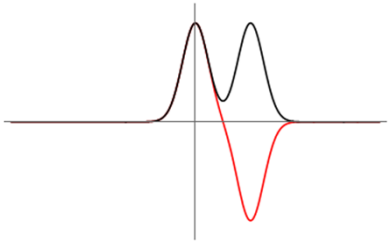
- Magnetic probe
  of spin memory



- Mechanical probe
  of resistive memory



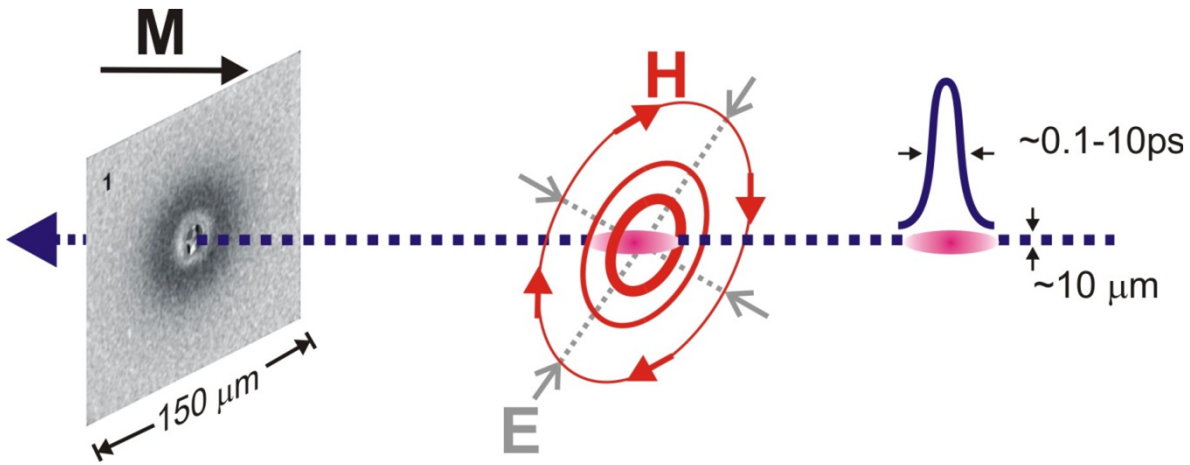
- Two bunch probe use



Accelerated Bunch

- Magnetic and electric fields
  (plane wave, radial polarized)
- Intense and short pulses
  (peak: E ~ 1 V/Å, B ~ 30 T)

$$H \sim \frac{I}{r} \sim \frac{Q/\tau}{r}$$



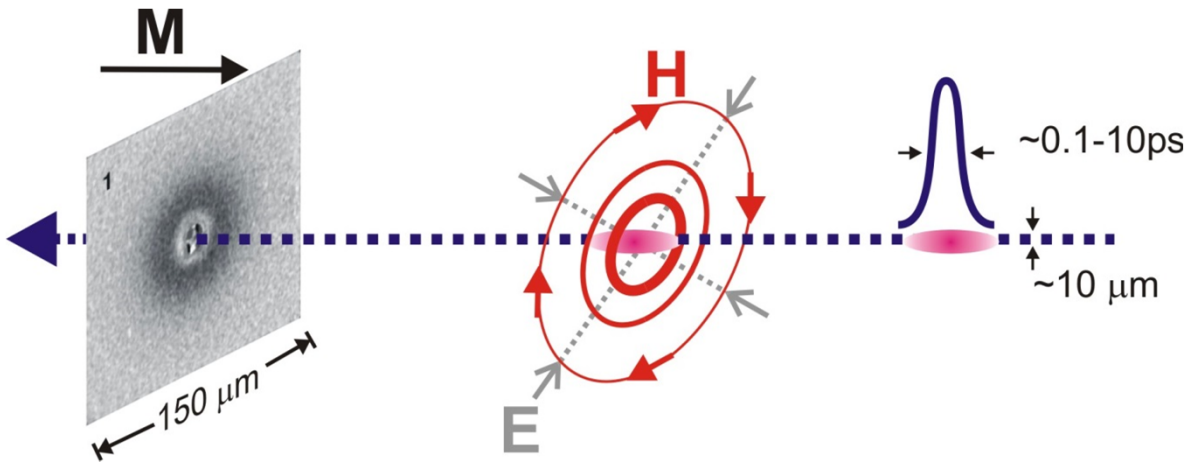
$$E = c \times B$$

Electron/Positron Bunch Parameters

Energy	10 GeV
Charge	2 nC / 1 nC
Bunch Length	20 μm
Spot Size	20 μm
Peak Current	10 kA / 5 kA
Bunch Spacing	0-500 μm

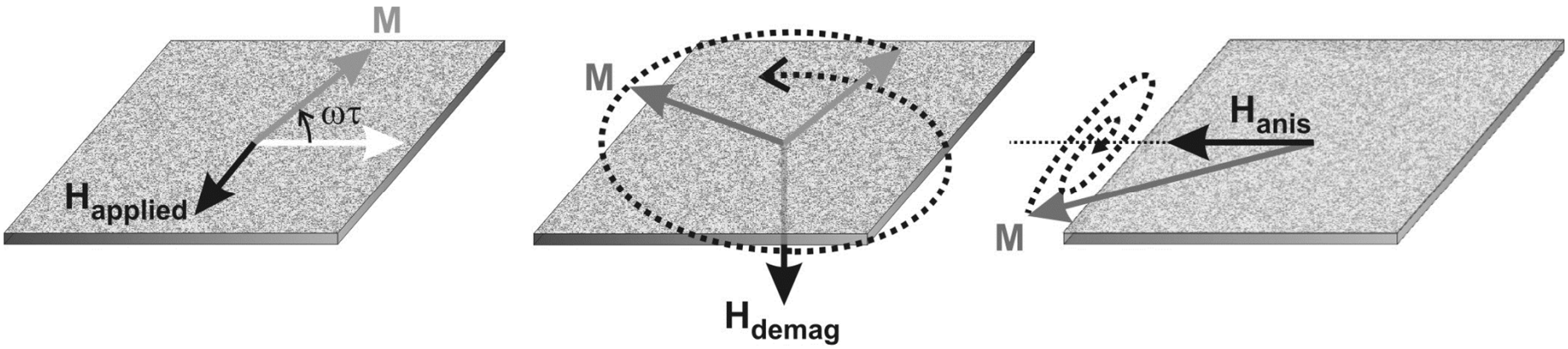
Probing magnetic spin systems

- Pass bunch through magnetic thin films
- Image pattern afterwards



Precessional Magnetization Reversal

3 Step Process



Field Pulse Kick

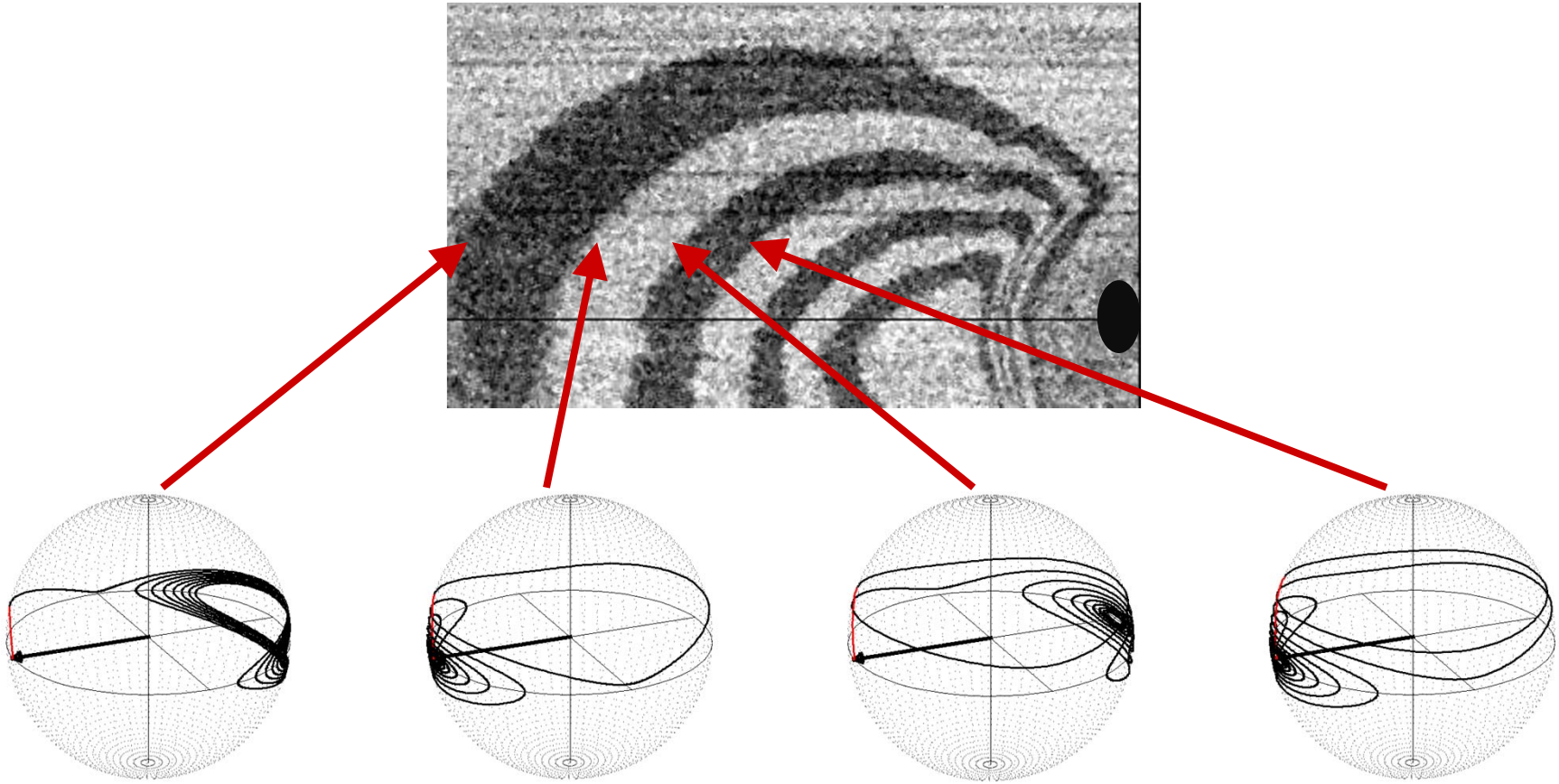
$\theta = \omega\tau$

Rotations Around H_{demag}

$\varphi = \pi, 2\pi, 3\pi \ldots$

Final Alignment

Dynamics of Magnetization

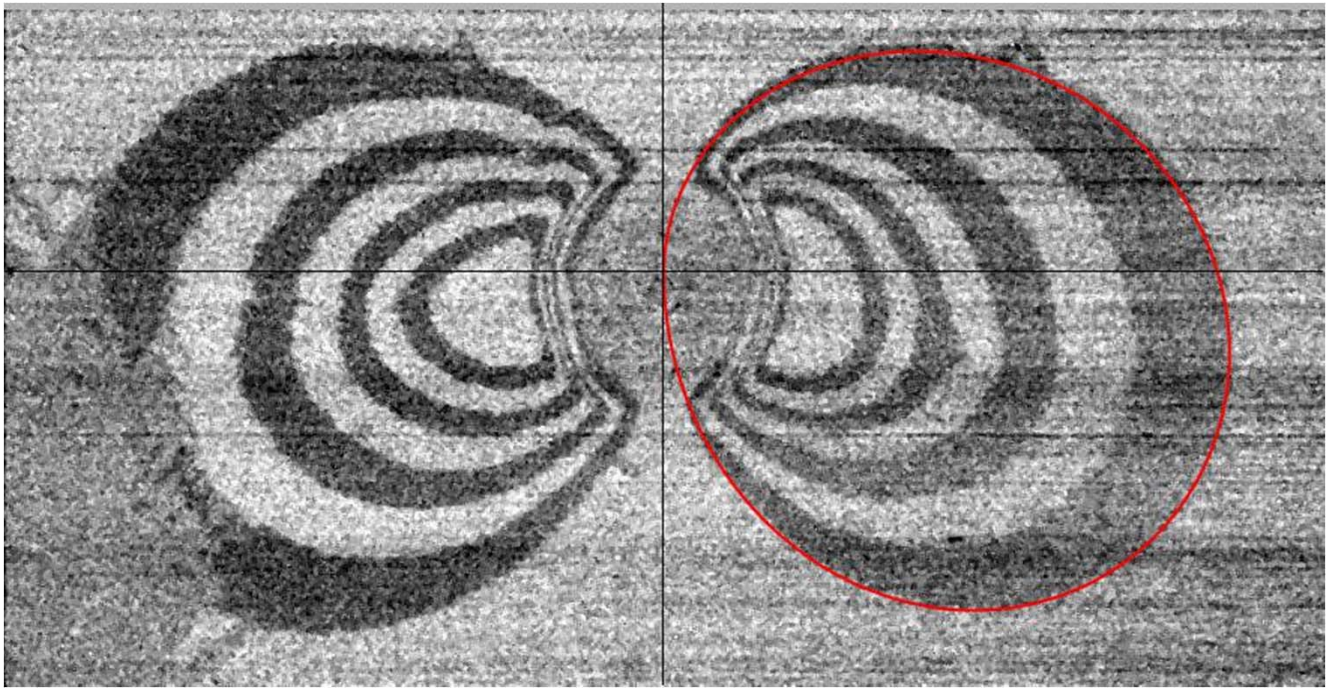


Damping dissipates the energy pumped into the system → ring location

Extra Torque

- Distortion from circle → extra torque
- Ratio of extra / magnetic torque:

$$\kappa = \frac{T_E}{T_H} = 0.15$$



Sample:
4nm Ag / 60 ML Fe / W(110)

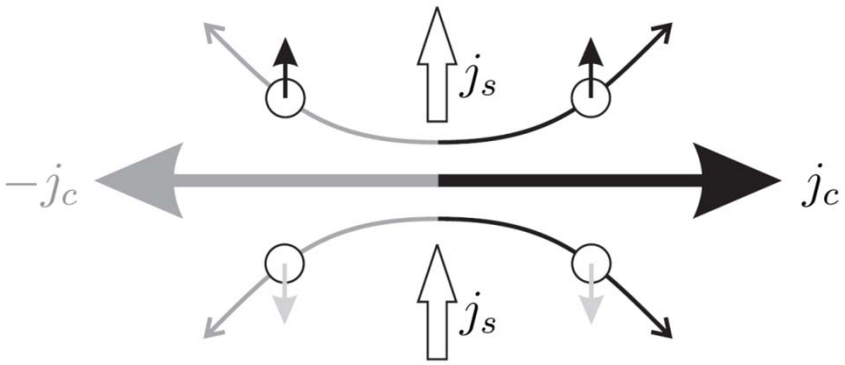
In polar coordinates

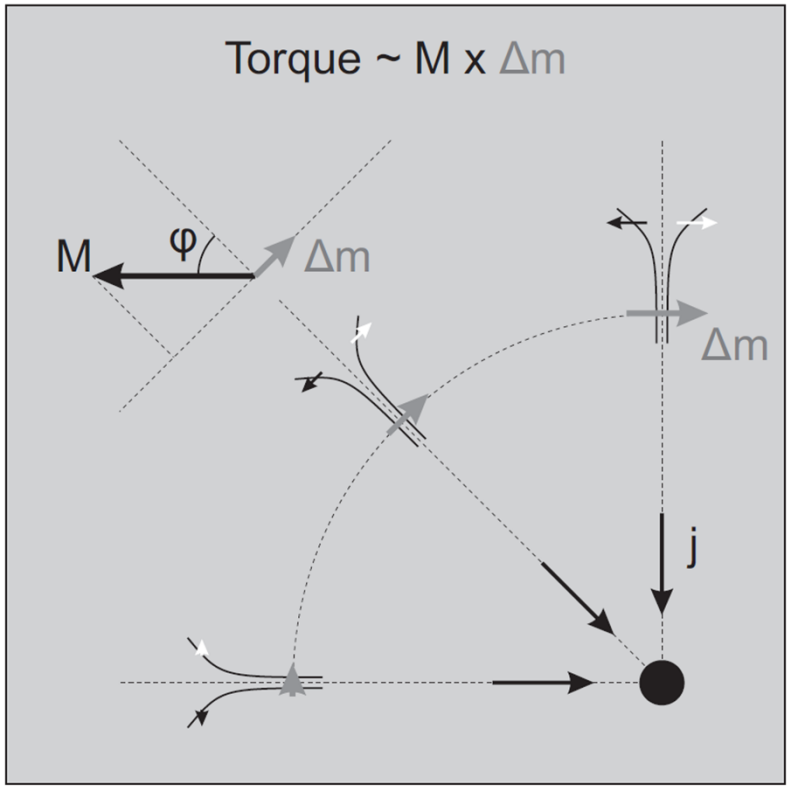
$$\frac{\cos\theta - \kappa \cdot \sin 2\theta}{r} = const$$

Spin-Orbit Coupling and Spin Accumulation

Anomalous Hall Effect

Spin-orbit coupling bends trajectory of e^- in eddy currents j_c → *Spin current* j_s





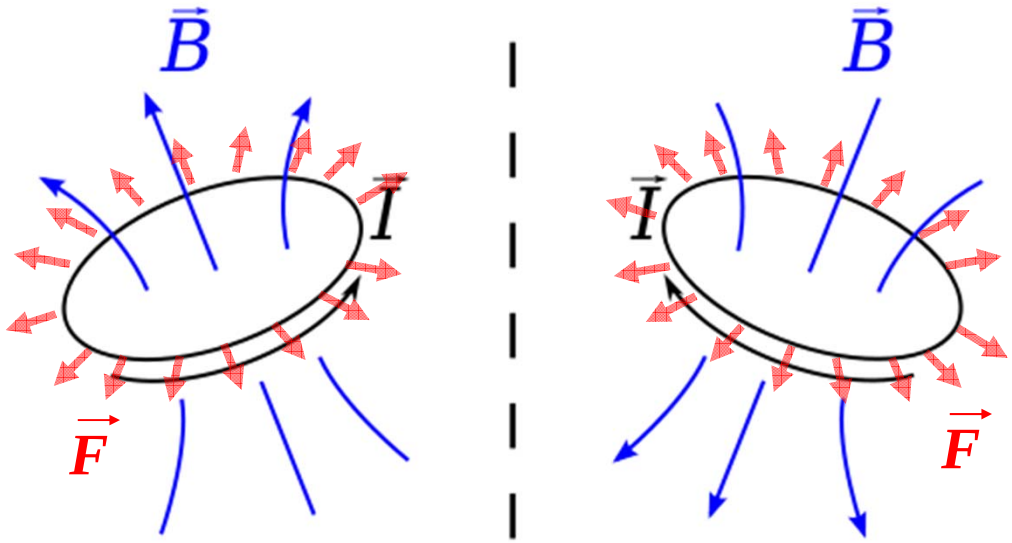
A second e^+ bunch:

- Subtract from magnetic torque
- Adds to this extra torque

Spin current → Spin accumulation → Torque Δm

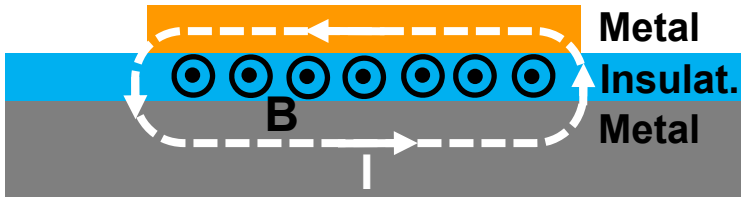
FACET Provides A Lorentz Force Switch

- **Tensile self-force on a coil w current**
- **Transient *B*** → **transient force**
- **EM coupling to MIM structure**



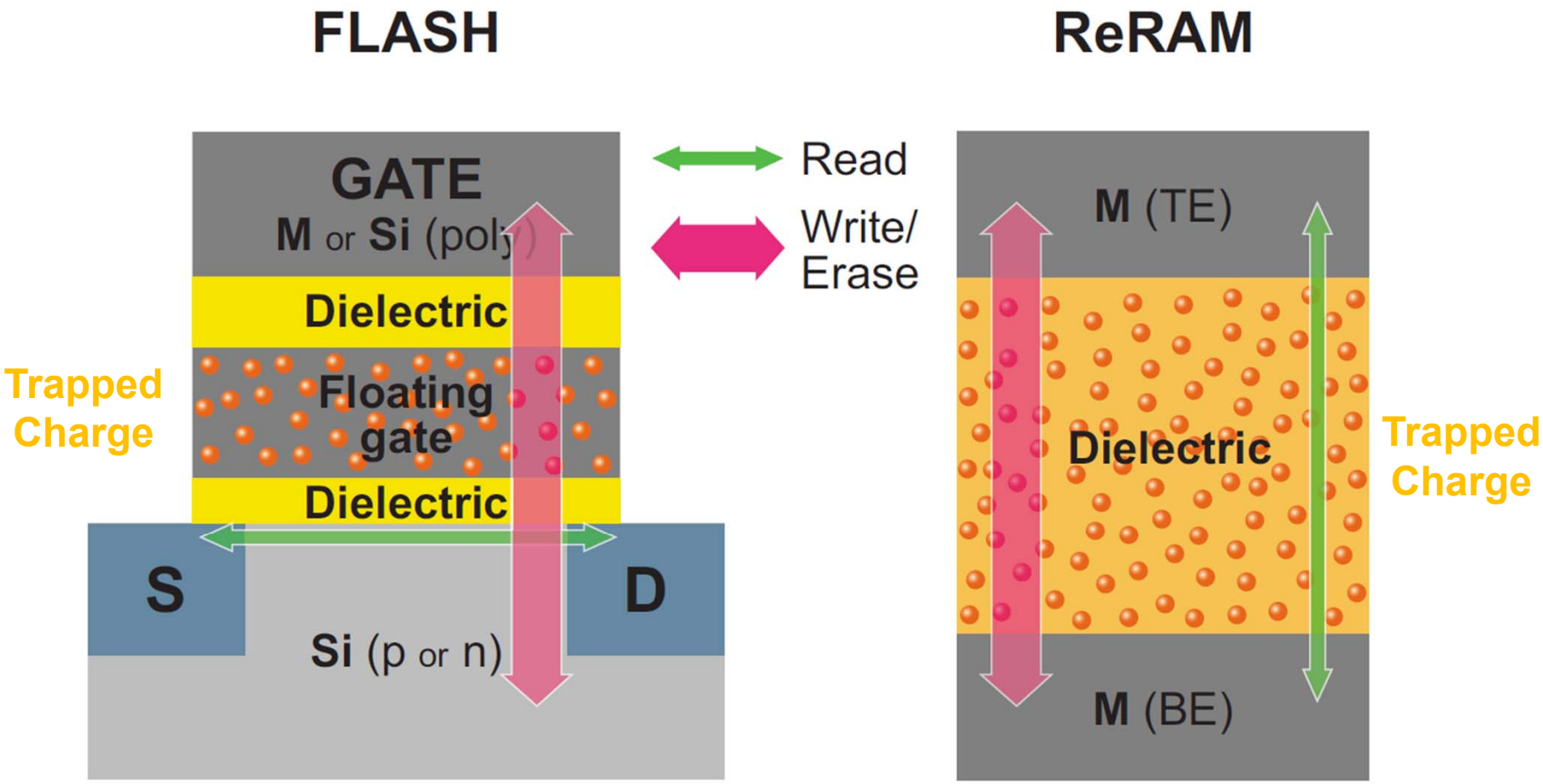
Force ~ *I* x *B*

Δt ~ 0.1 ps !



Nonvolatile Memory

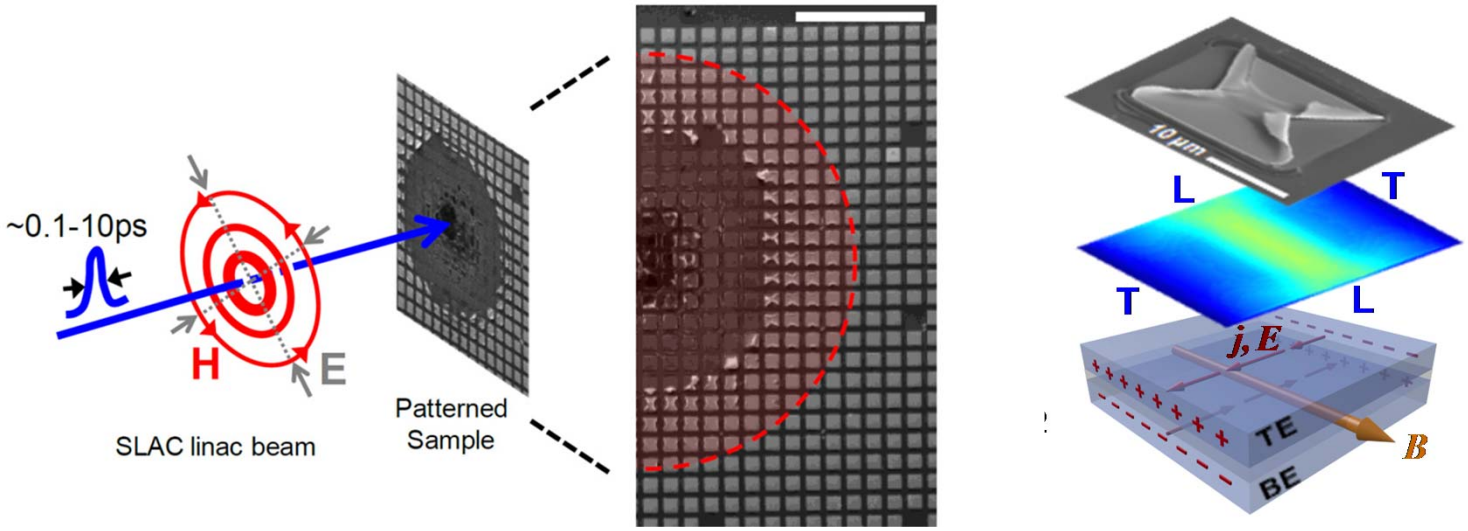
Voltage-Time dilemma due to read-write paths



Open Questions

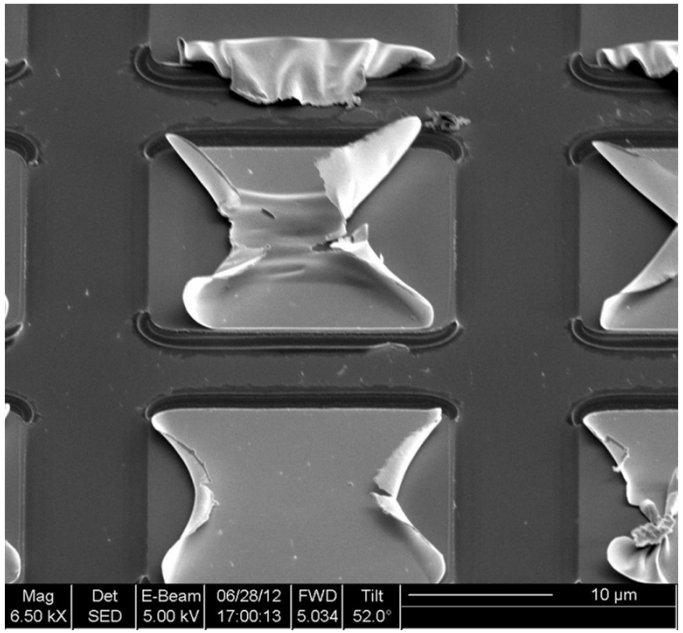
- Temporal limit of switching?
- **Role of atom lattice in trapping?**
- **Fast electro-mechanical probe!**

Principle of the experiments

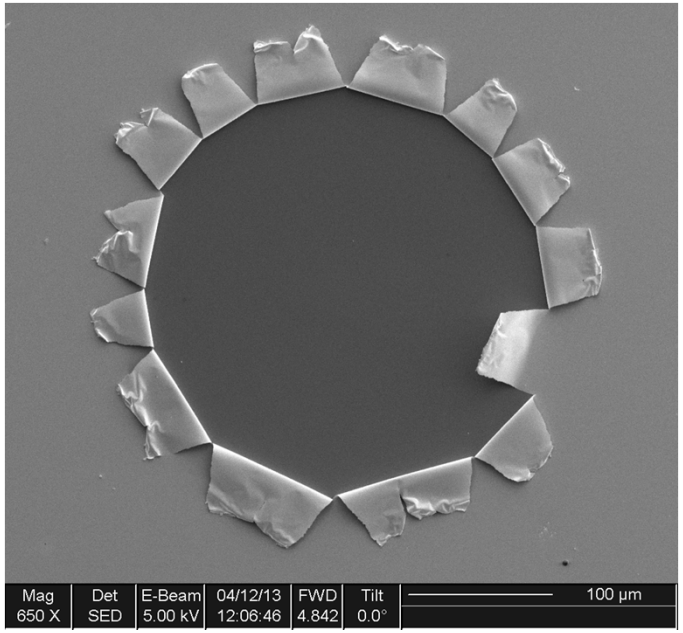


Array of devices exposed to e-beam
Probe and image afterwards

Top Electrode Damage

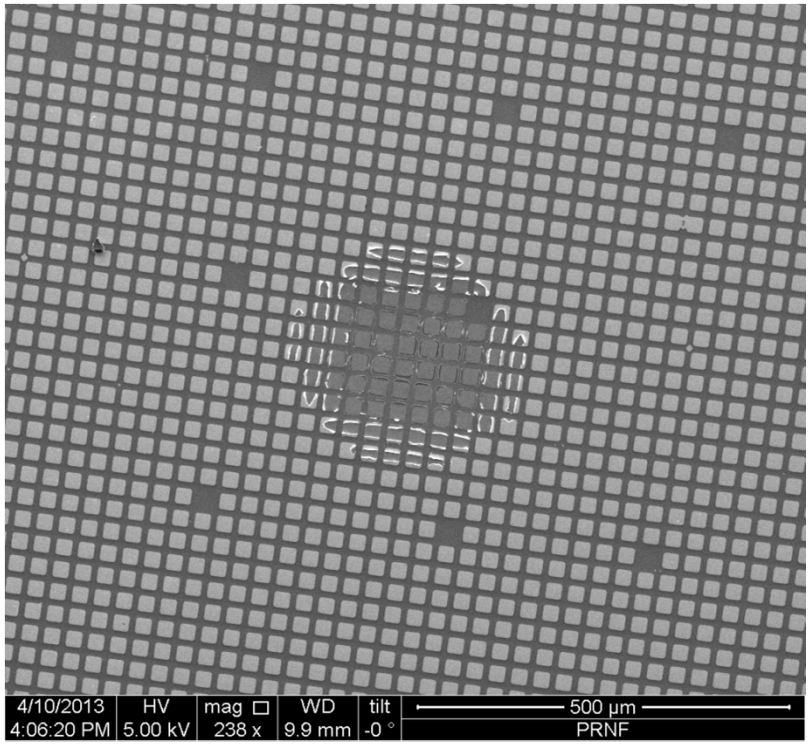


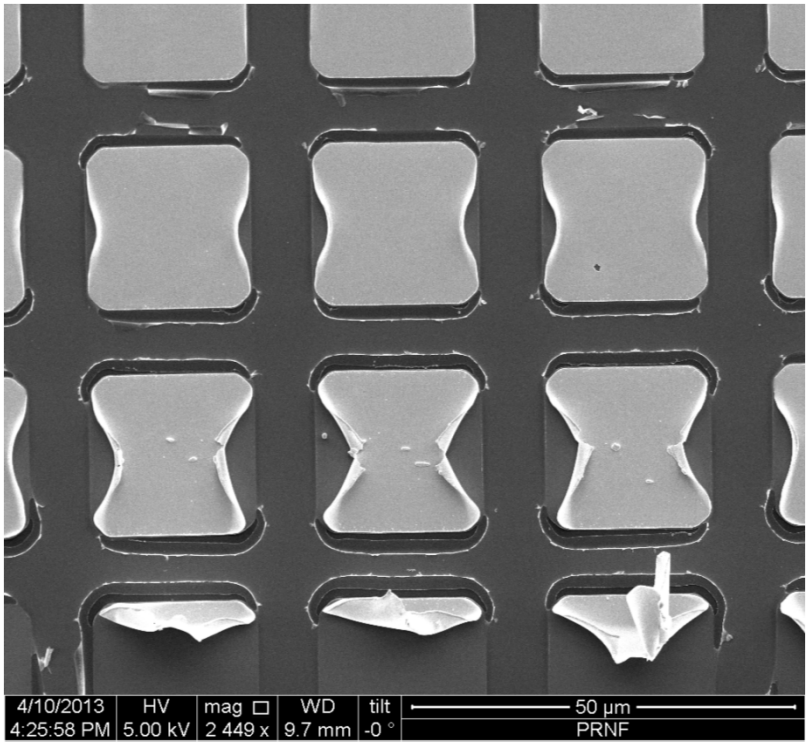
Rectangular Pad



Continuous Film

Top Electrode Damage



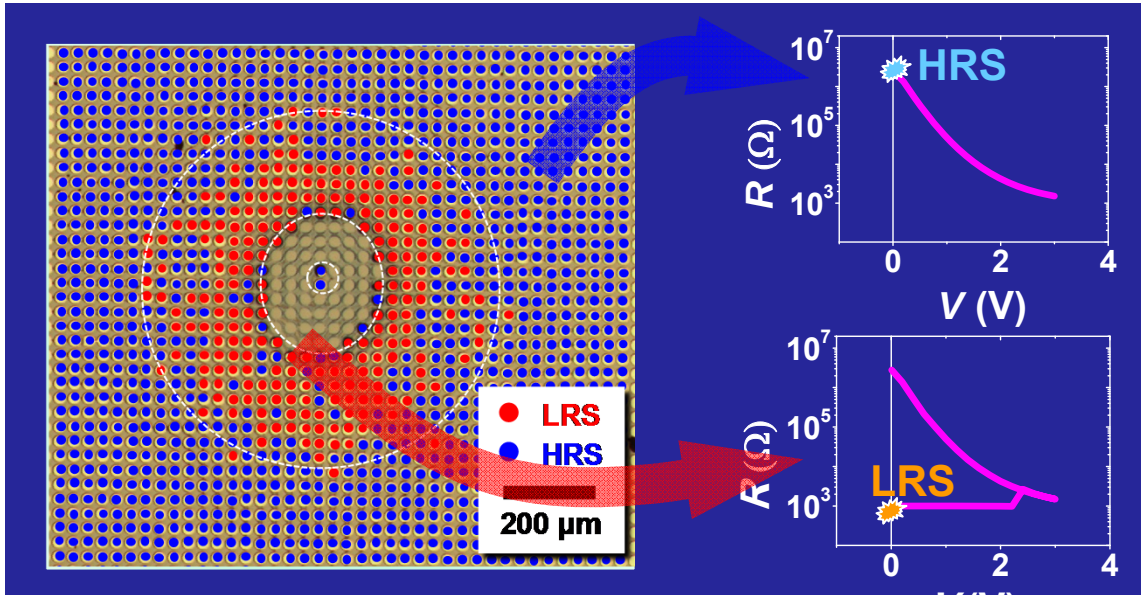


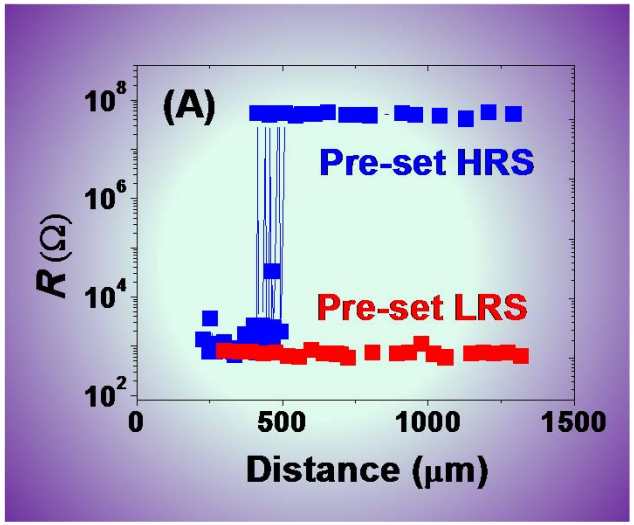
Switching Results

Only High-R state is switched

Mechanical effect points to relaxation of atomic bonds

Solve voltage-time dilemma by electron-lattice interaction





All Cells Preset to HRS

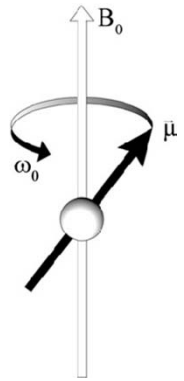
Opportunities at FACET

- ***Strong*** **100 fs field impulse**
- **Well coupled to 10s μm MIM device**
- **Magnetic-mechanical-electric probe**
- **Time scale ~ Atomic motion**

Scaling of Effects

- Spin precession angle

$$\theta = \omega\tau \sim B\tau \sim \frac{I}{r}\tau \sim \frac{Q}{r}$$



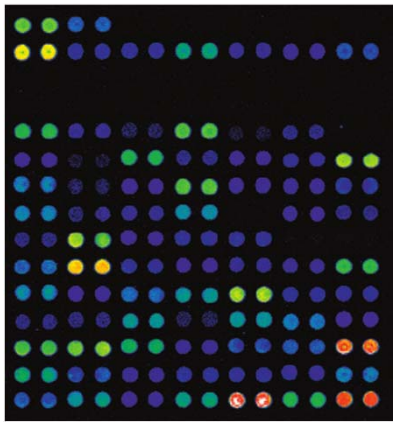
- Mechanical Impulse

$$\Delta p = F\tau \sim B^2\tau \sim \frac{I^2}{r^2}\tau \sim \frac{QI}{r^2}$$

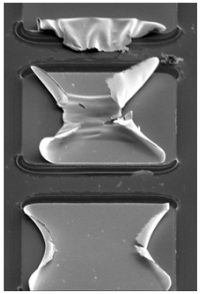
- Maximize charge Q and current I
- Minimize bunch spot size σ_r

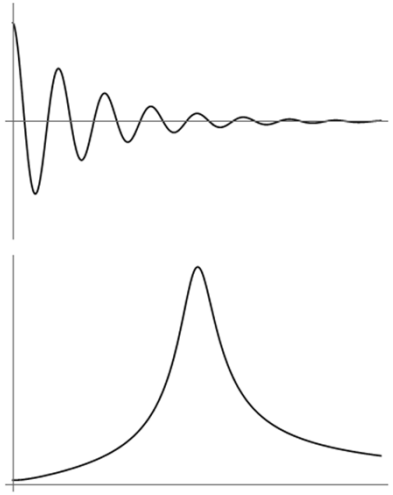
Experiments with two bunches

- Method: "*double pump - probe later*"
- For systems with memory
- Take many shots, image later
  (like in DNA microarray)



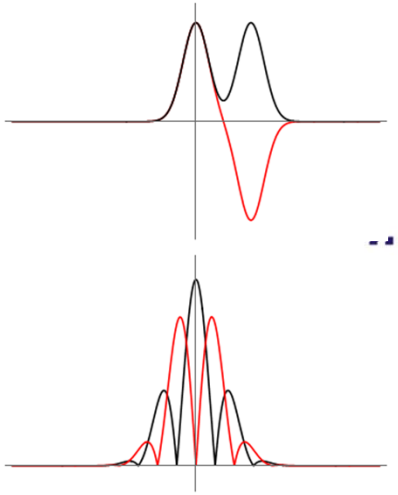
- Extract system response from convolution

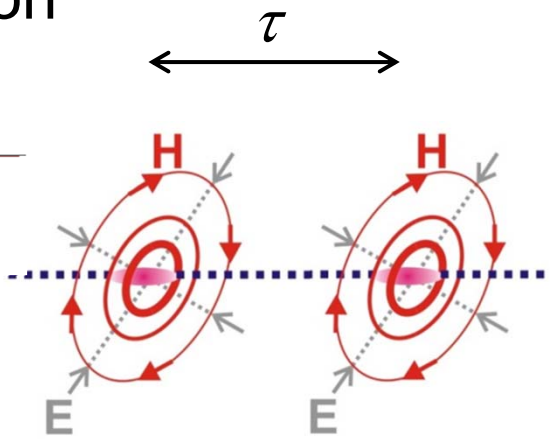




Time

Freq





End