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STRUCTURAL MODIFICATION OF MgO/CoFeB USING A LOW ENERGY ION BEAM FROM AN ASSISTED DEPOSITION SOURCE

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Presentation Outline

I. Motivation

II. Ion Beam Assisted Deposition

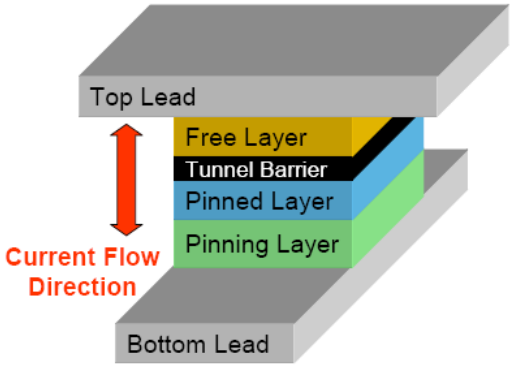
III. X-ray Diffraction Data of MgO and CoFeB/MgO/CoFeB

IV. HR-TEM of CoFeB/MgO multilayers

V. Conclusions

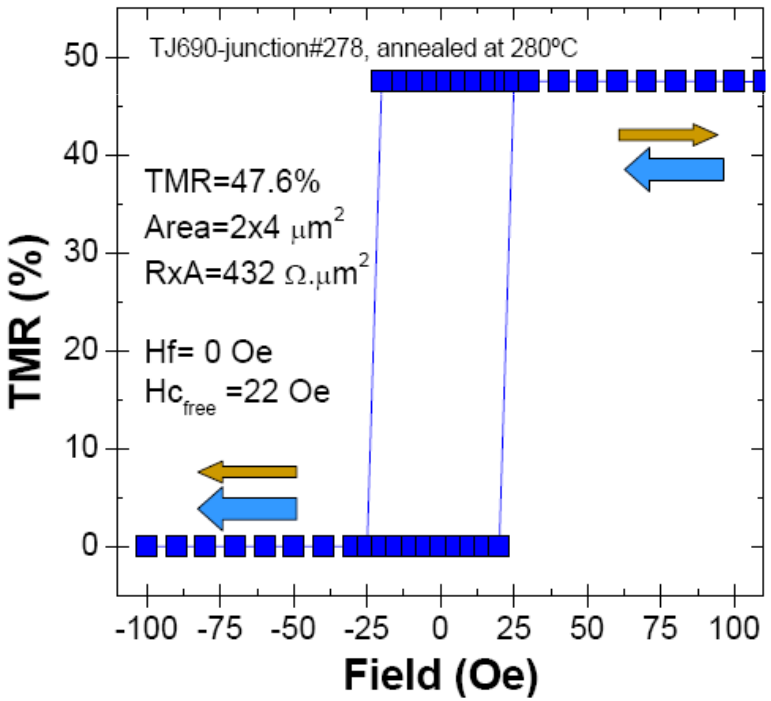
Motivation

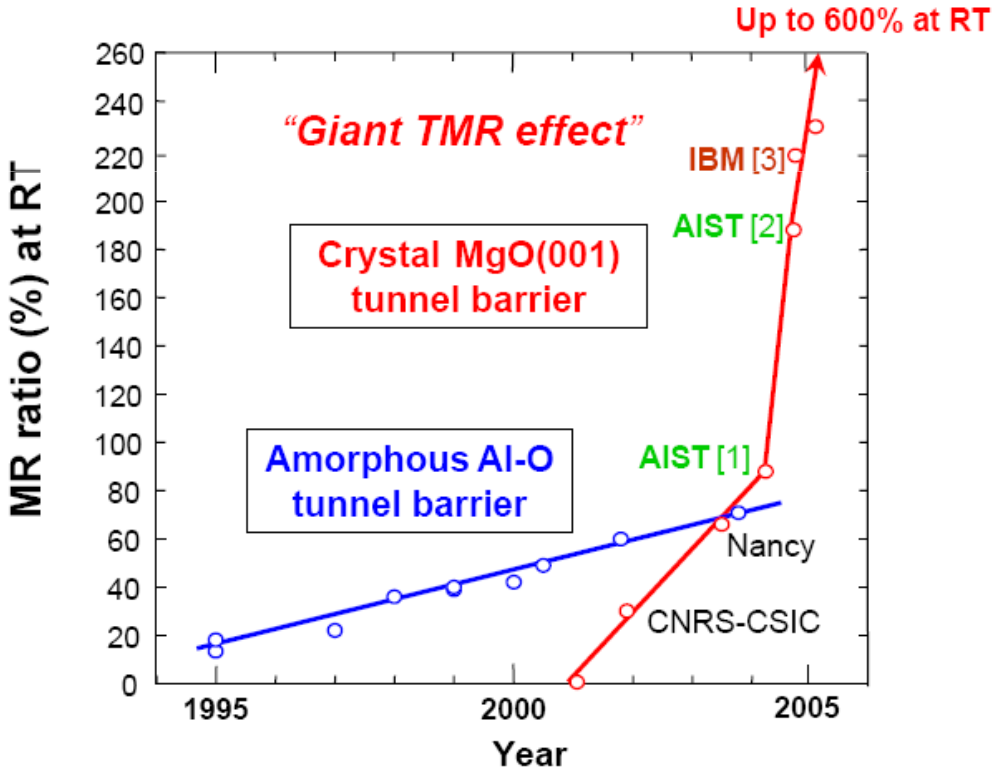
Magnetic Tunnel Junctions



AlOx MTJs : Magnetic Field Sensors, HDD read heads

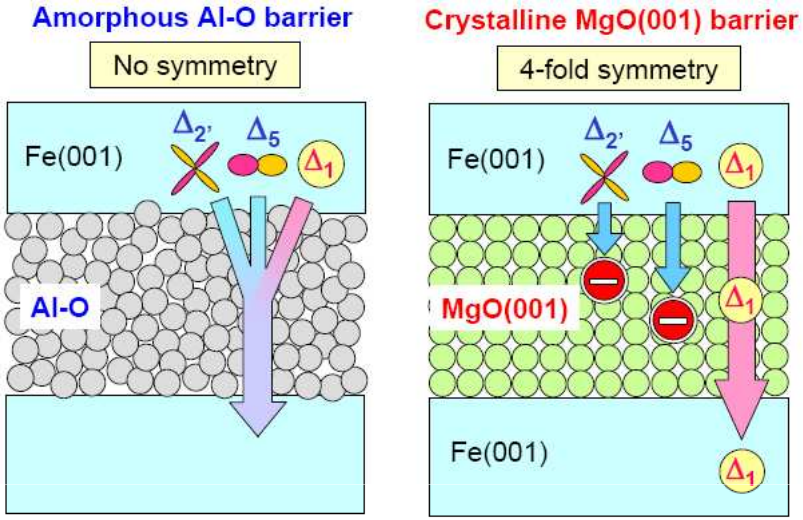
MgO MTJs : non-volatile memories (MRAM), Spin Transfer Nano-Oscillators (Wi-Fi, novel CMOS magnetic hybrid devices)

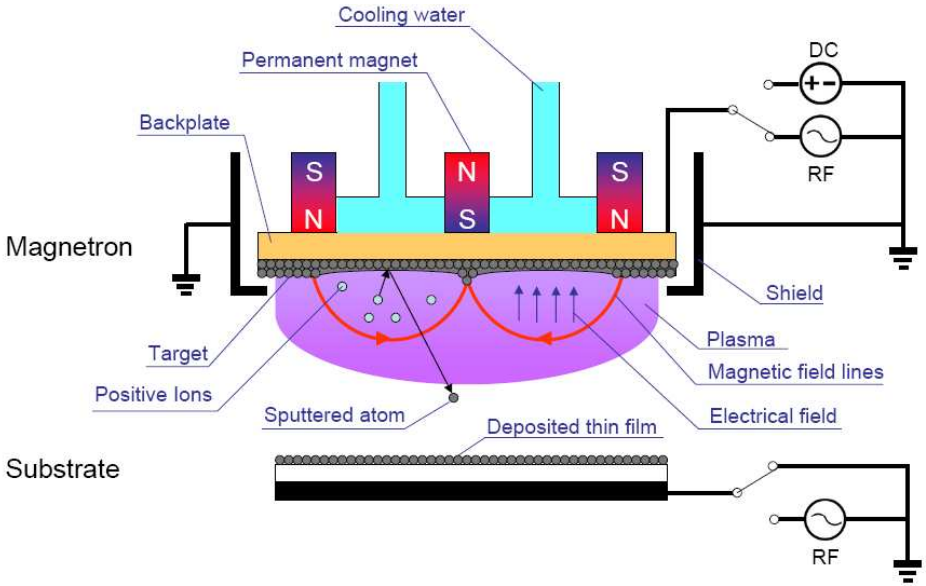




Motivation

PVD Deposited MgO Magnetic Tunnel Junctions





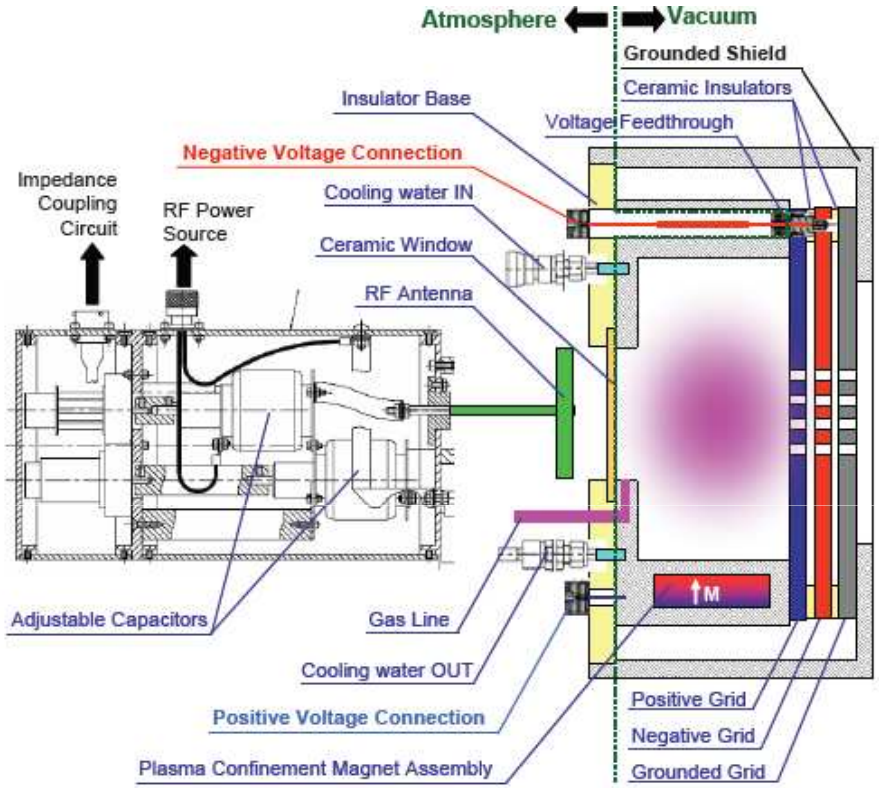
As deposited	After annealing
amorphous CoFeB	bcc [100] CoFeB
[100] MgO	[100] MgO
amorphous CoFeB	bcc [100] CoFeB
~ 10% TMR	~300% TMR

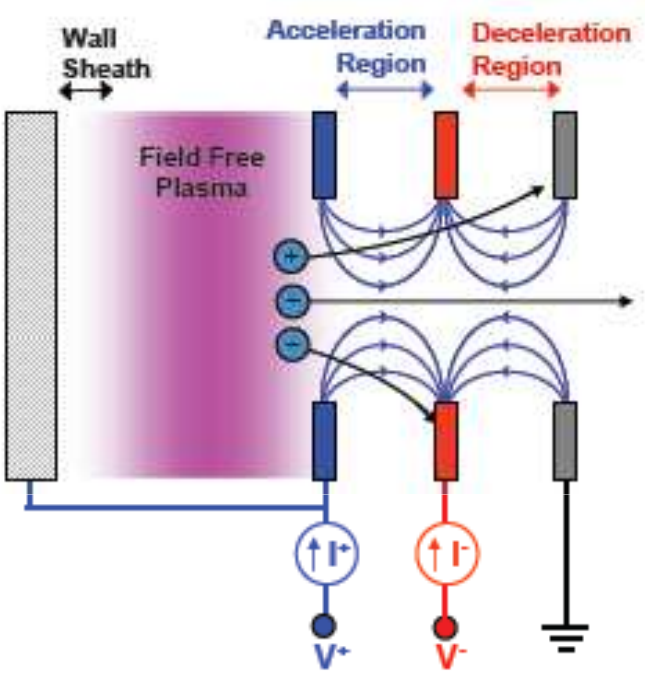
PVD systems :

- coherently tunneling is routinely achieved
- TMR is strongly system dependent
- best TMR values are still far away from theoretical predictions (>1000%).
- Small number of parameters available (pressure, RF power, distance to substrate)

Ion Beam Deposition

Kauffmann type Ion Beam Guns





V^+ : Ion Kinetic Energy

I^+ : Ion Beam Current

V^- : Extraction Voltage

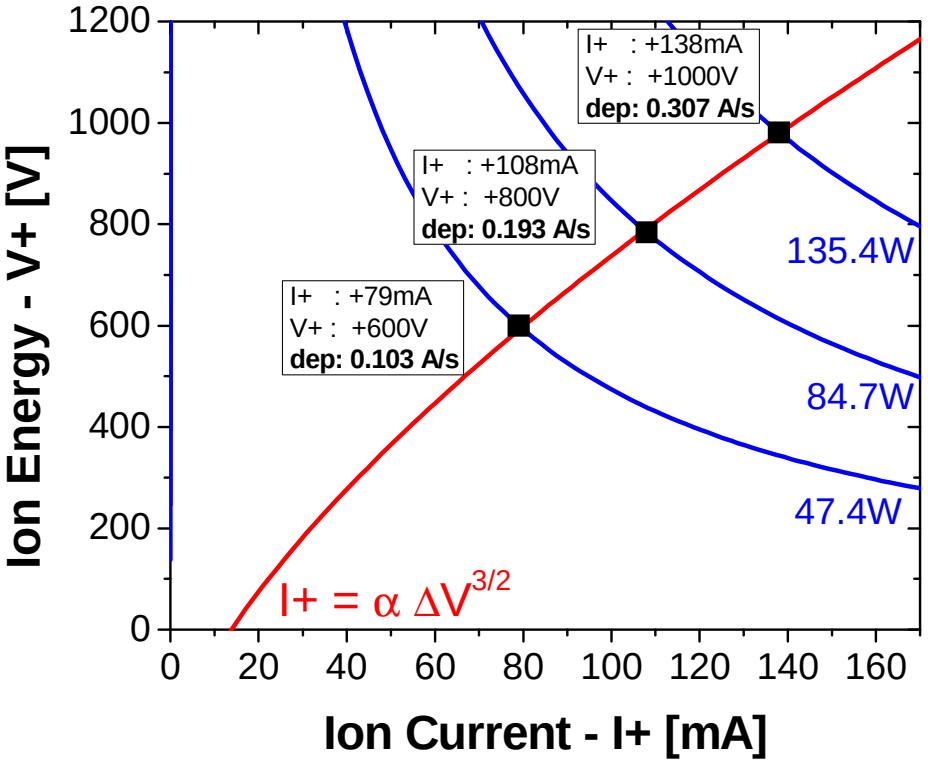
I^- : Ion Beam Divergence

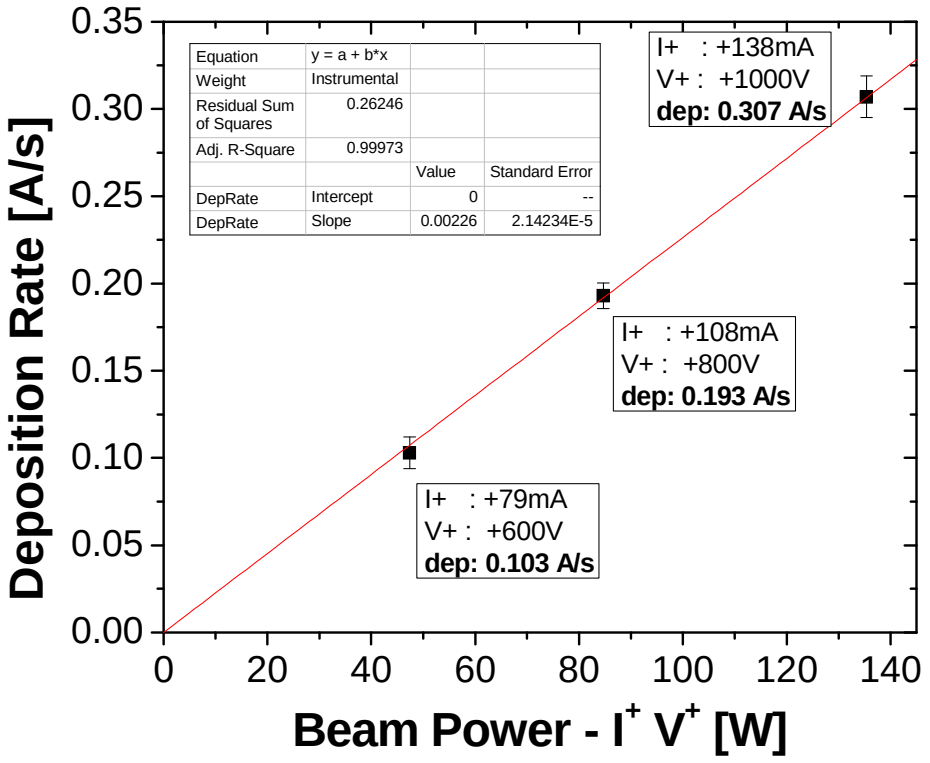
Number of Ions extracted per unit of time and the energy per ion are independent parameters!

Constant Beam Profile : $I^+ = \alpha (V^+ - V^-)^{3/2}$

Ion Beam Deposition

MgO Ion Beam Deposition – Not Assisted





As deposited

amorphous CoFeB
amorphous MgO
amorphous CoFeB

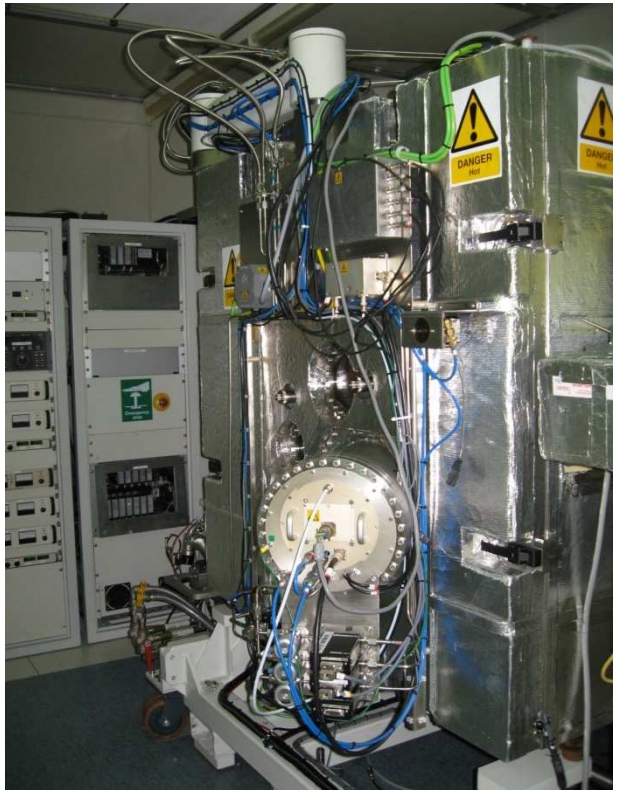
After annealing

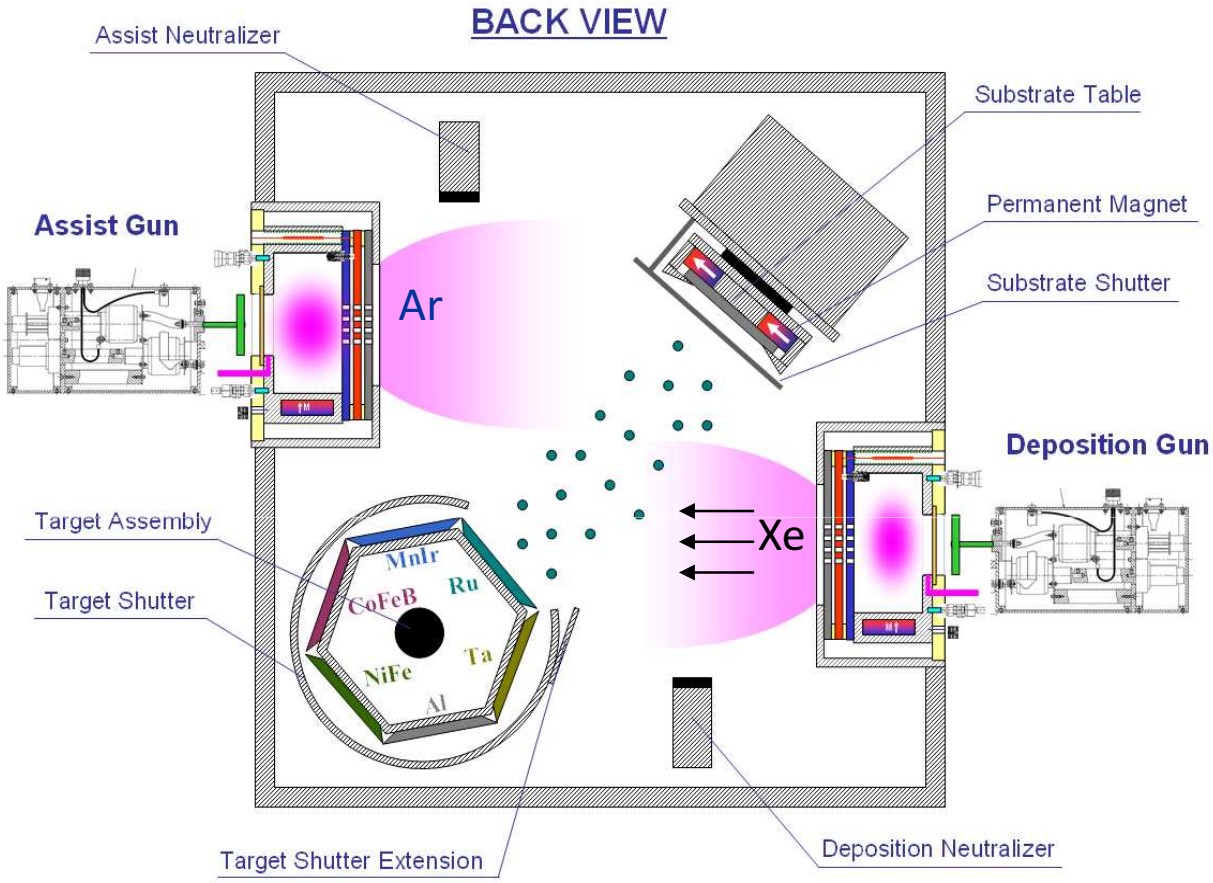
amorphous CoFeB
[100] MgO
amorphous CoFeB

Ion Beam deposited MgO is always amorphous in the as-deposited state!

Ion Beam Assisted Deposition

Nordiko 3600 Ion Beam Deposition Tool





Ion Beam Assisted Deposition of MgO :

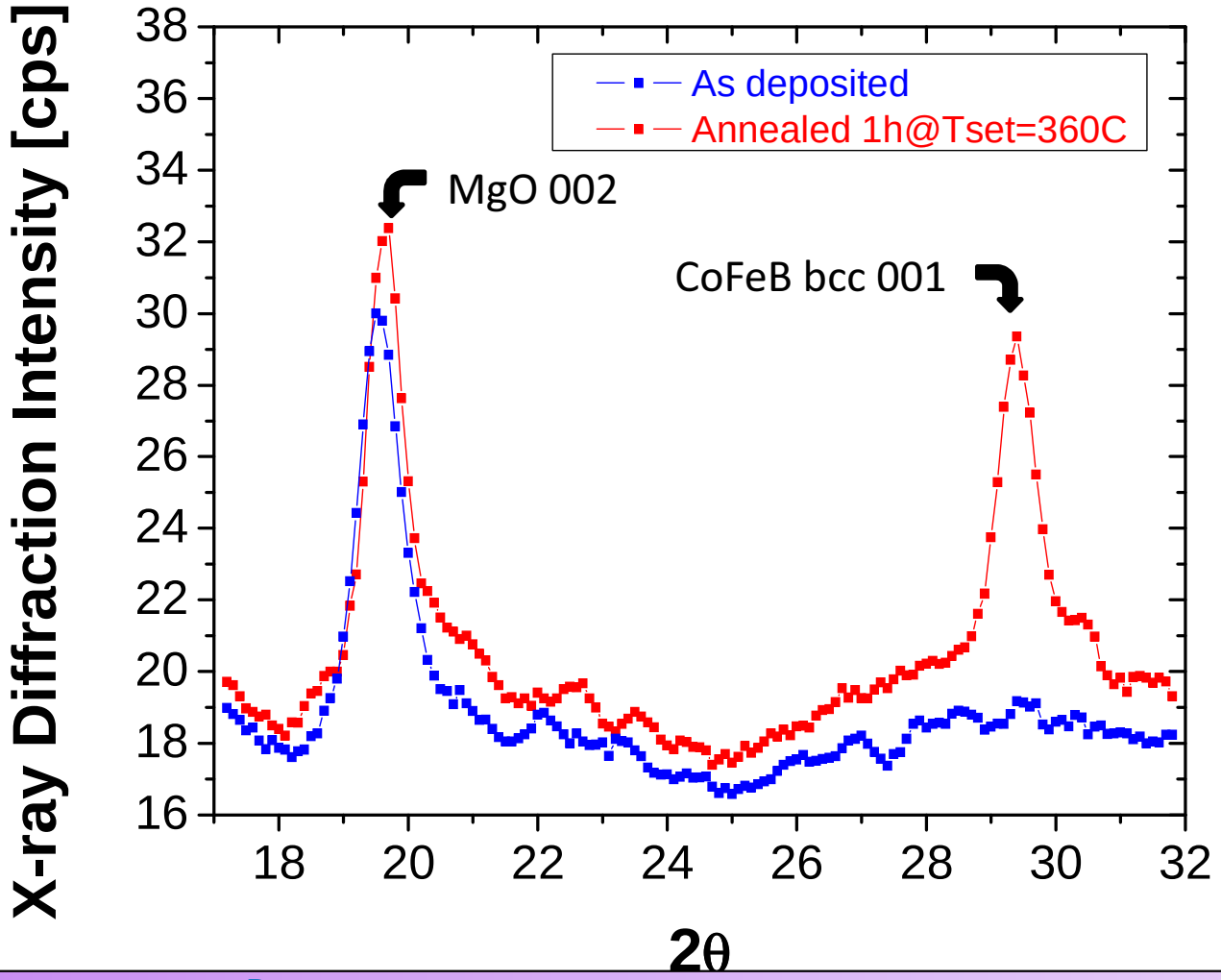
- An assistance Ar ion beam, directed to the substrate is used to provide extra energy to the atoms as they are deposited
- This extra energy can promote the crystalization of the MgO

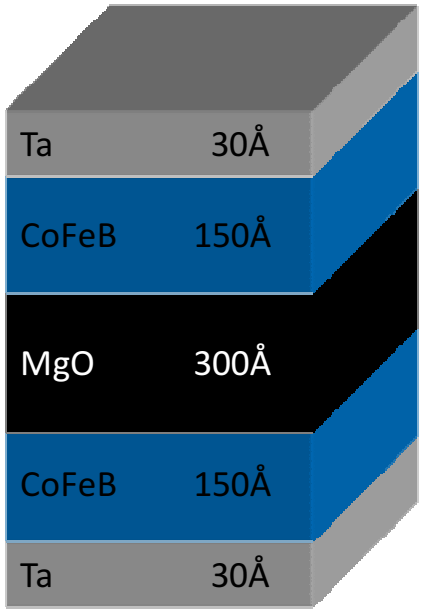
Ion Beam Assisted Deposition

XRD diffraction of CoFeB/MgO/CoFeB stacks

MgO Deposition Conditions:

Deposition Gun +138mA; +1000V/-275V | Assist Gun +95mA; +350V/-300V





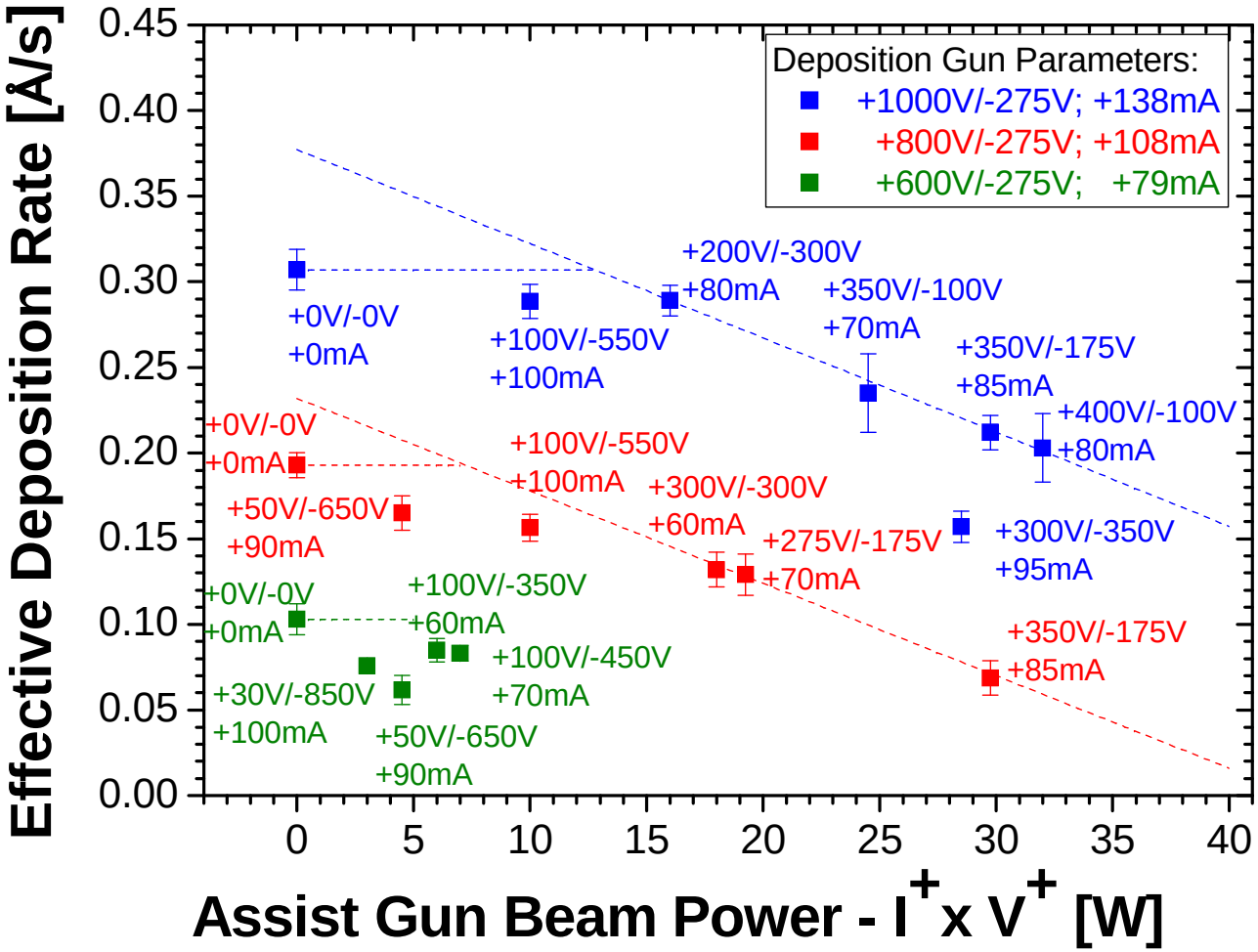
Ion Beam Assisted Deposition

Deposition rate versus Assist Gun Beam Power

Effective Deposition Rate = Deposition Rate – Etch Rate

Deposition Rate α Dep Gun Beam Power ($I^+ V^+$)

Etch Rate α Assist Gun Beam Power ($I^+ V^+$)



Ion Beam Assisted Deposition

Effect of Assist Gun Ion Energy (V^+)

Effective Deposition Rate = Deposition Rate – Etch Rate

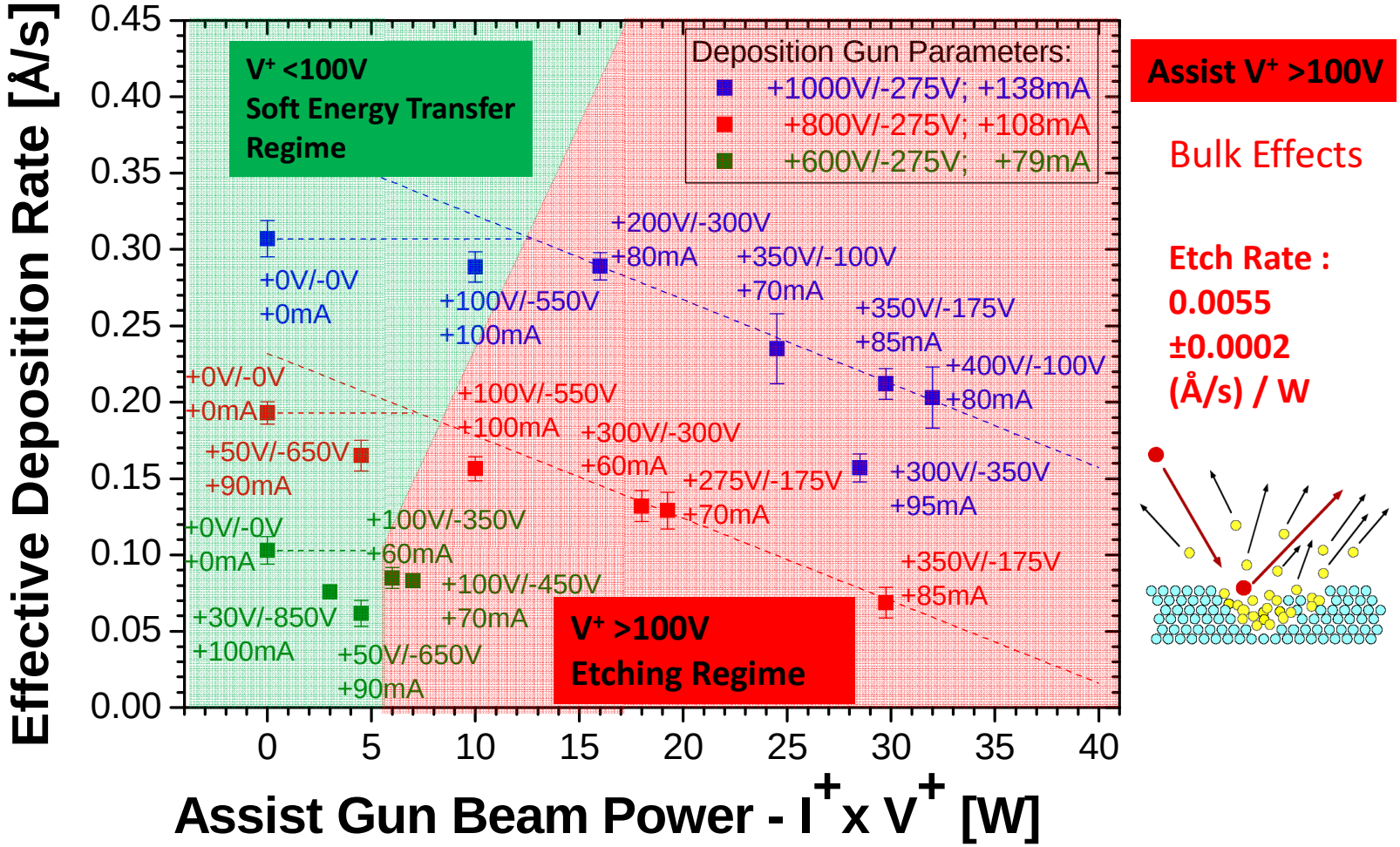
Deposition Rate α Dep Gun Beam Power ($I^+ V^+$)

Etch Rate α Assist Gun Beam Power ($I^+ V^+$)

Assist V^+ <100V

Surface Effects

Assist beam ions enhance the mobility of surface atoms, without removing them.



Assist V^+ >100V

Bulk Effects

Etch Rate : 0.0055 ±0.0002 (Å/s) / W

Ion Beam Assisted Deposition

Effect of Assist Gun Beam Current (I^+)

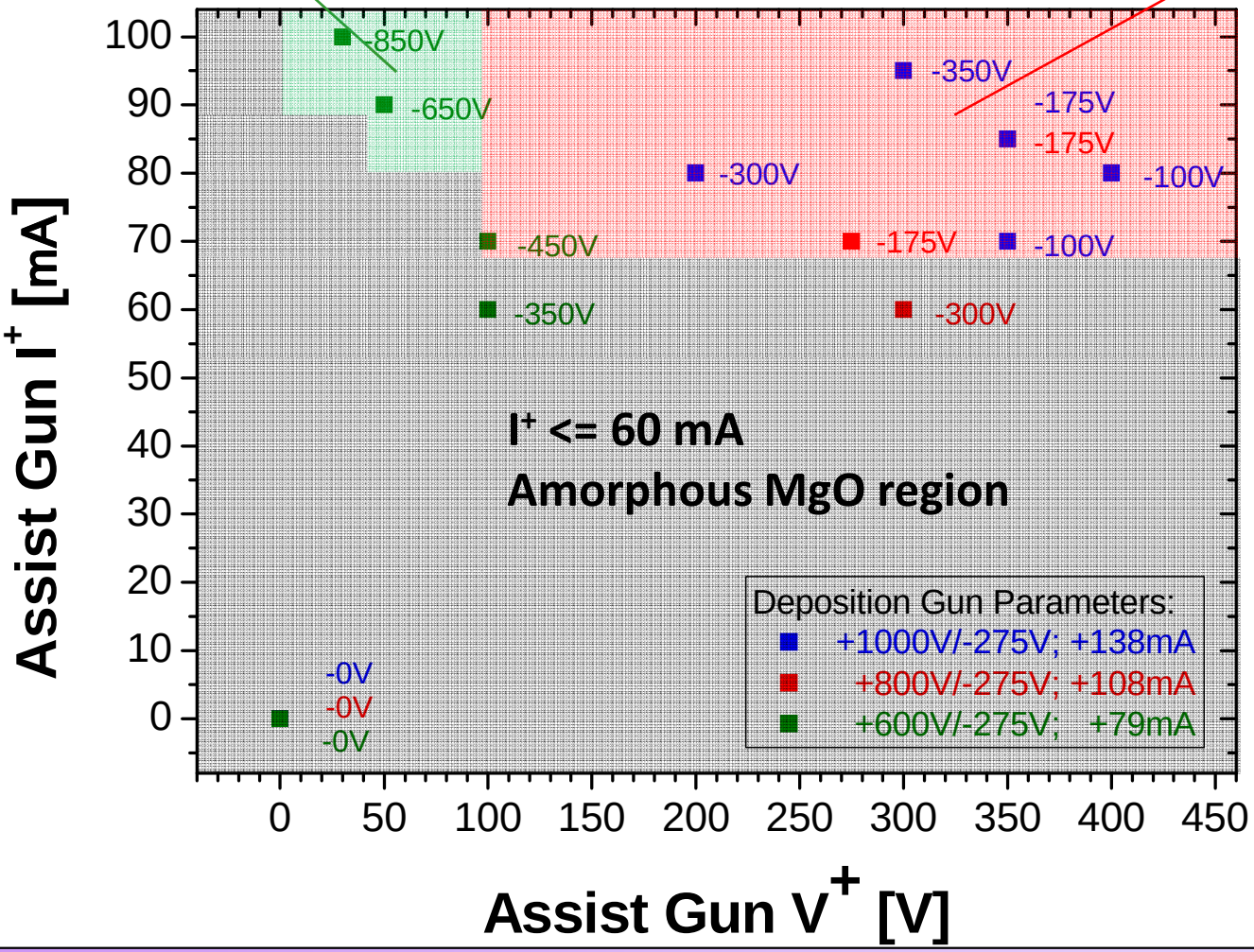
Soft Energy Transfer Regime

I^+ >=80mA is required

Etch Regime

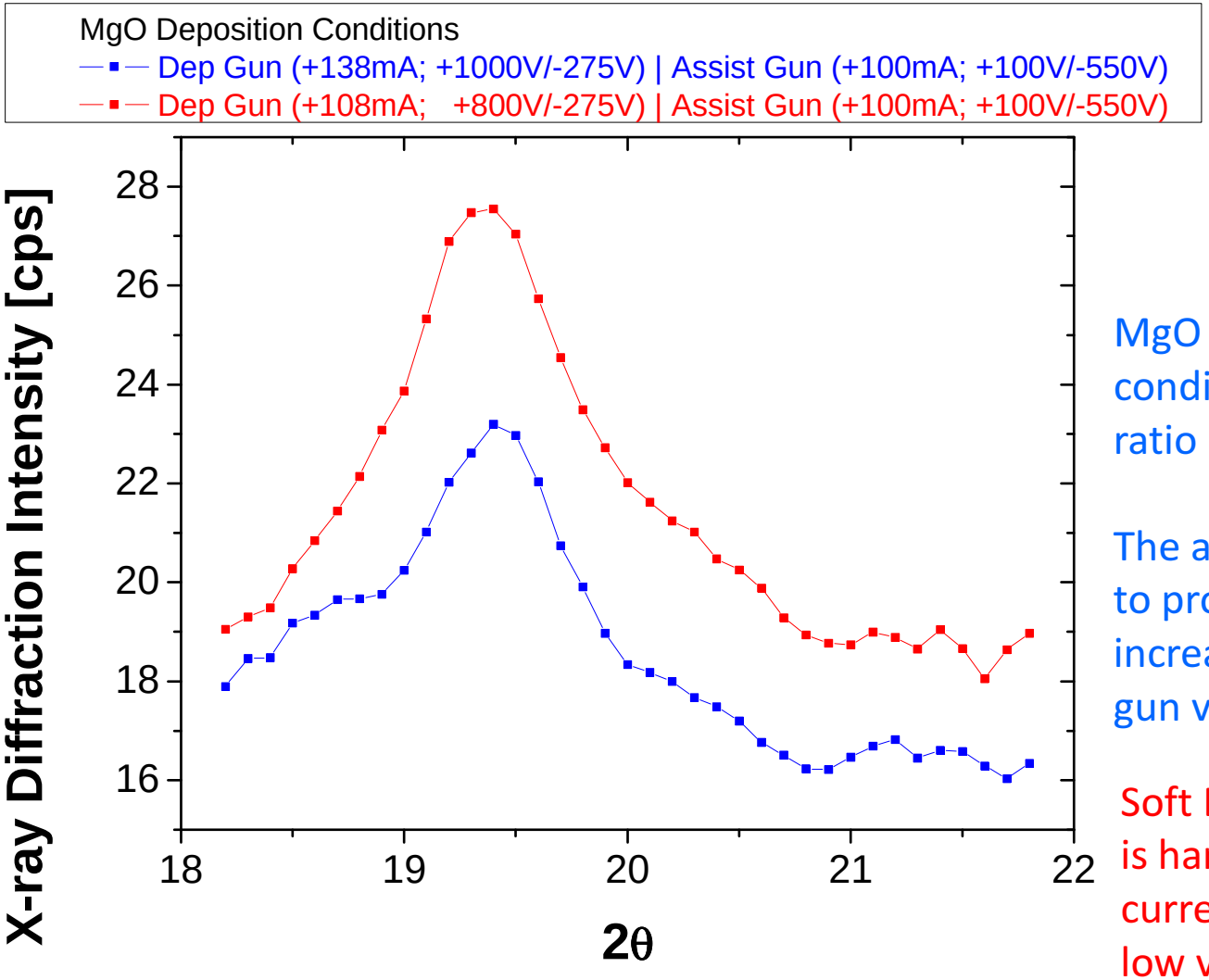
I^+ >=70mA

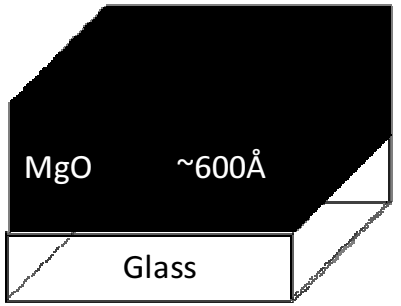
Crystalline MgO



Ion Beam Assisted Deposition

Effect of Assist Gun Beam Current (I^+)





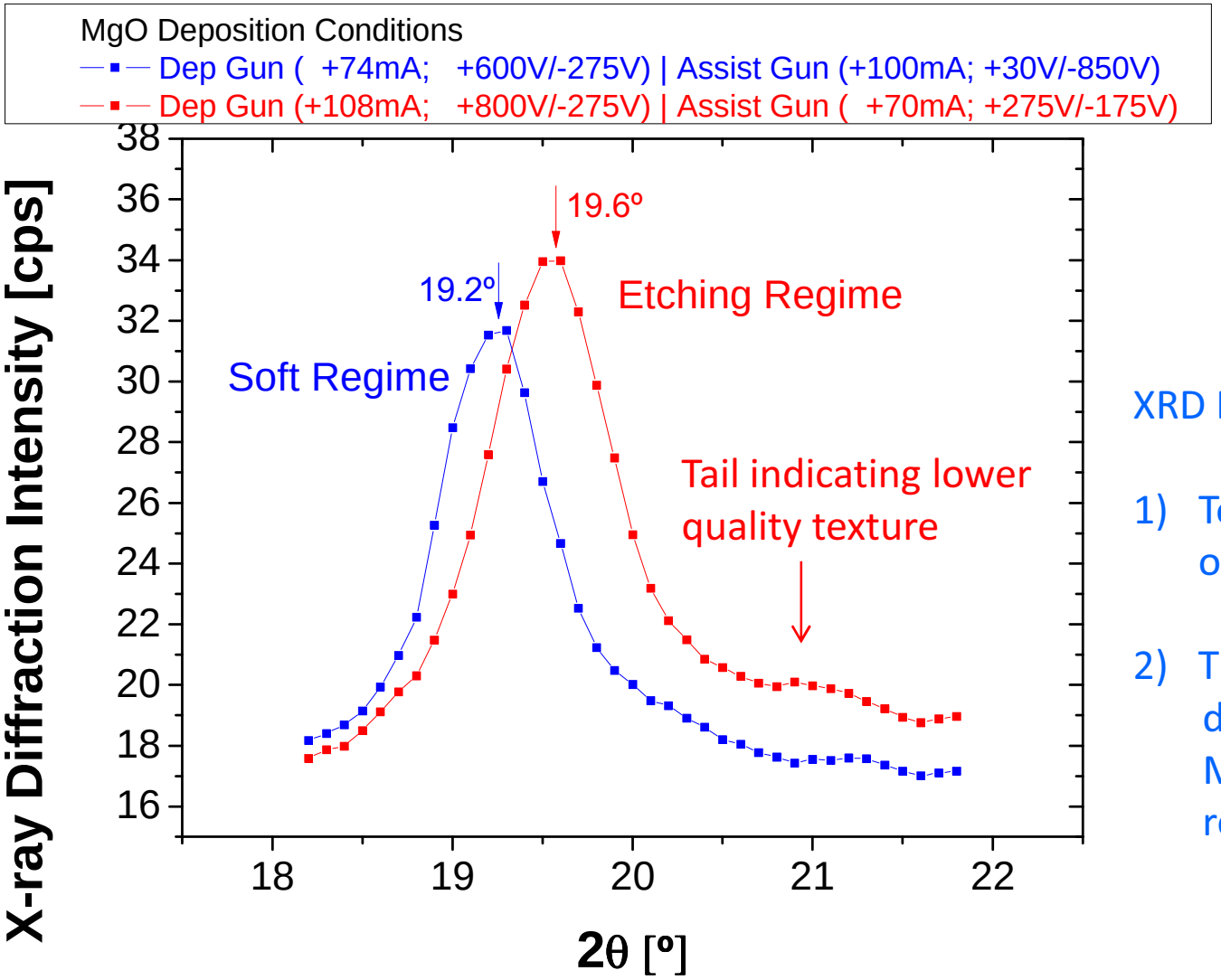
MgO texture is stronger for conditions with larger Ion/Atom ratio (Assist Gun I^+ / Dep Gun I^+).

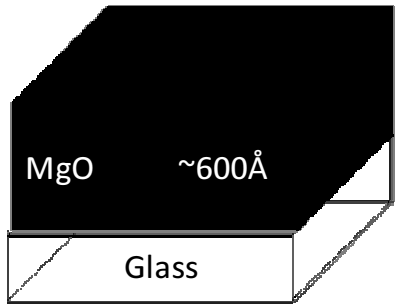
The assist gun current required to promote MgO crystallization increases with decreasing assist gun voltage .

Soft Energy Transfer Regime is hard to get : very large currents are required for very low voltages in order to crystallize MgO

X-ray Diffraction

Etching Regime versus Soft Regime : impact on MgO structure





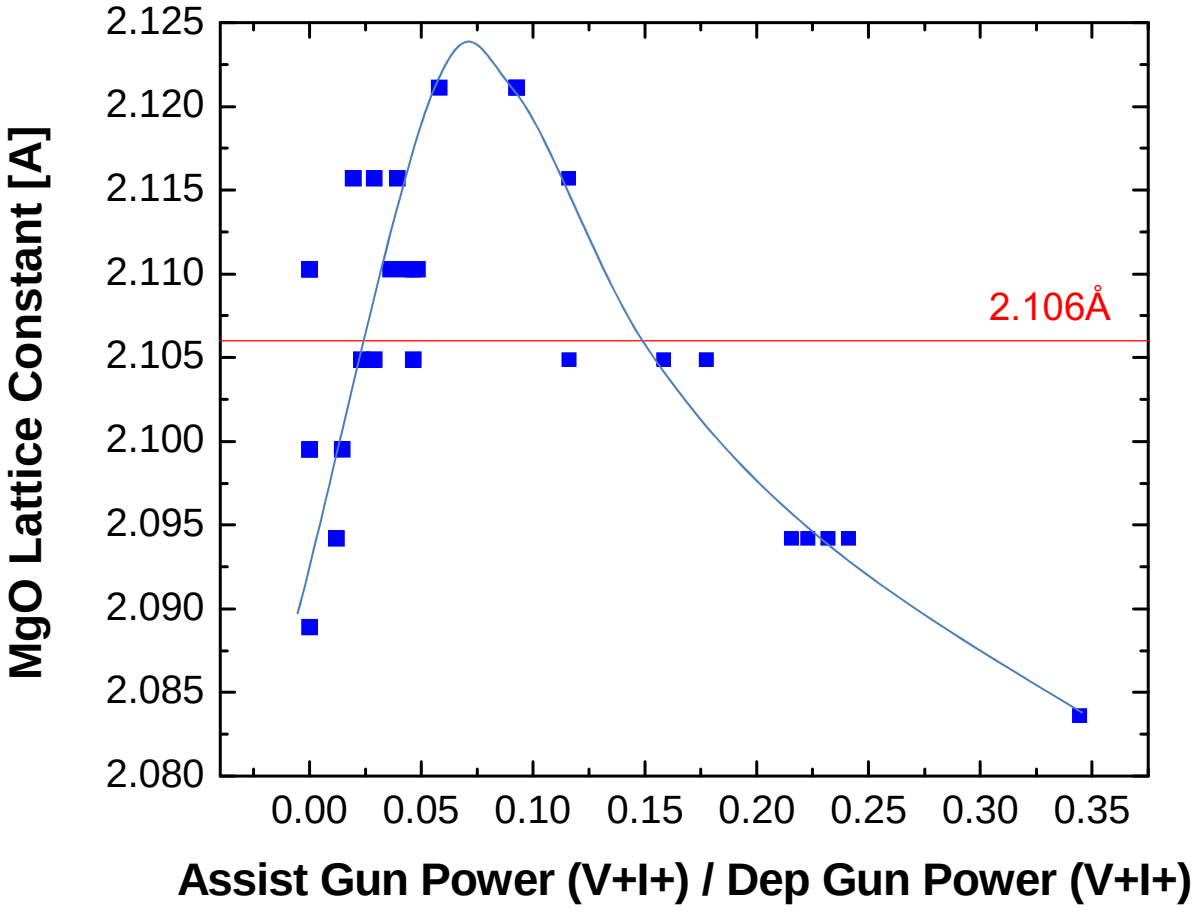
XRD Diffraction shows that:

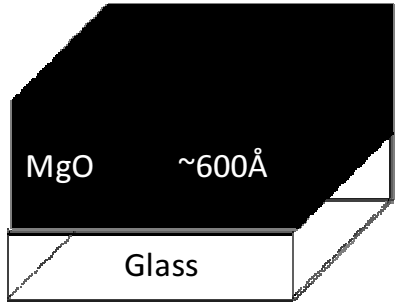
1) Textured MgO can be obtained in both regimes

2) There are structural differences between the MgO deposited in the two regimes considered

X-ray Diffraction

MgO lattice constant tuning





MgO lattice constant can be changed by setting the ration between the assist gun power and the deposition gun power.

This feature can be used to reduce the mismatch between the MgO and CoFeB lattices.

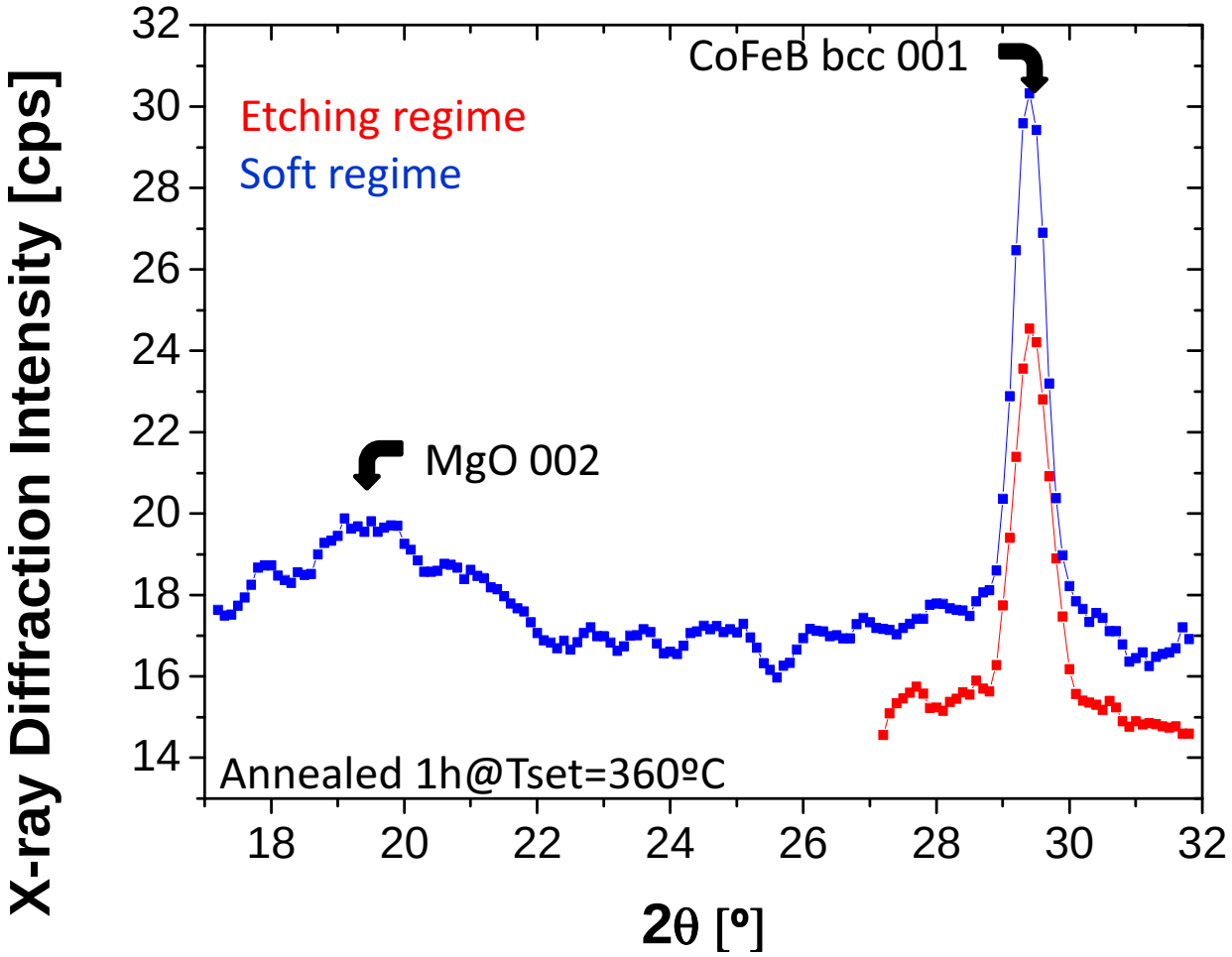
X-ray Diffraction

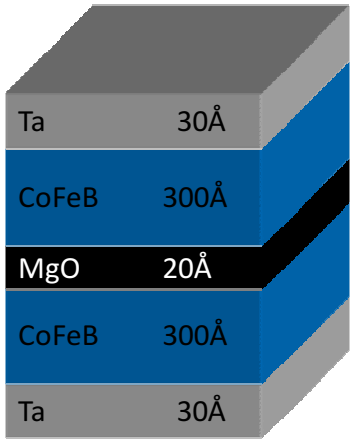
Etching Regime versus Soft Regime : structural differences

MgO Deposition Conditions

Dep Gun (+74mA; +600V/-275V) | Assist Gun (+100mA; +30V/-850V)

Dep Gun (+108mA; +800V/-275V) | Assist Gun (+70mA; +275V/-175V)



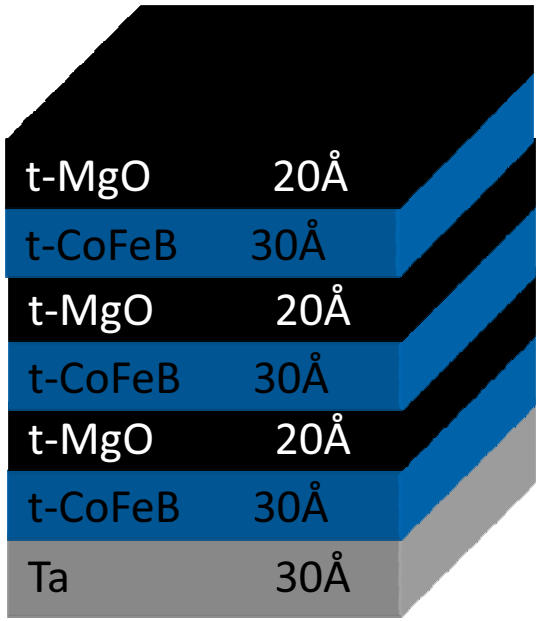


MgO deposited in the soft energy transfer regime is more efficient in promoting the texture of CoFeB upon annealing.

HRTEM

Stacks prepared thin MgO and thin CoFeB layers

10 bi-layers



MgO deposition conditions :

1) Soft Energy Transfer Regime

Deposition Gun : +600V; +74mA; 4.0 sccm Xe

Assist Gun : +30V/-850V; +100mA; 10sccmAr

2) Concurrent Etching Regime

Deposition Gun :+800V; +108mA; 4.0 sccm Xe

Assist Gun :+275V/-175V; +70mA; 10sccmAr

CoFeB and Ta deposition conditions :

Deposition Gun : +1200V/-275V; +170mA; 4.0 sccm Xe

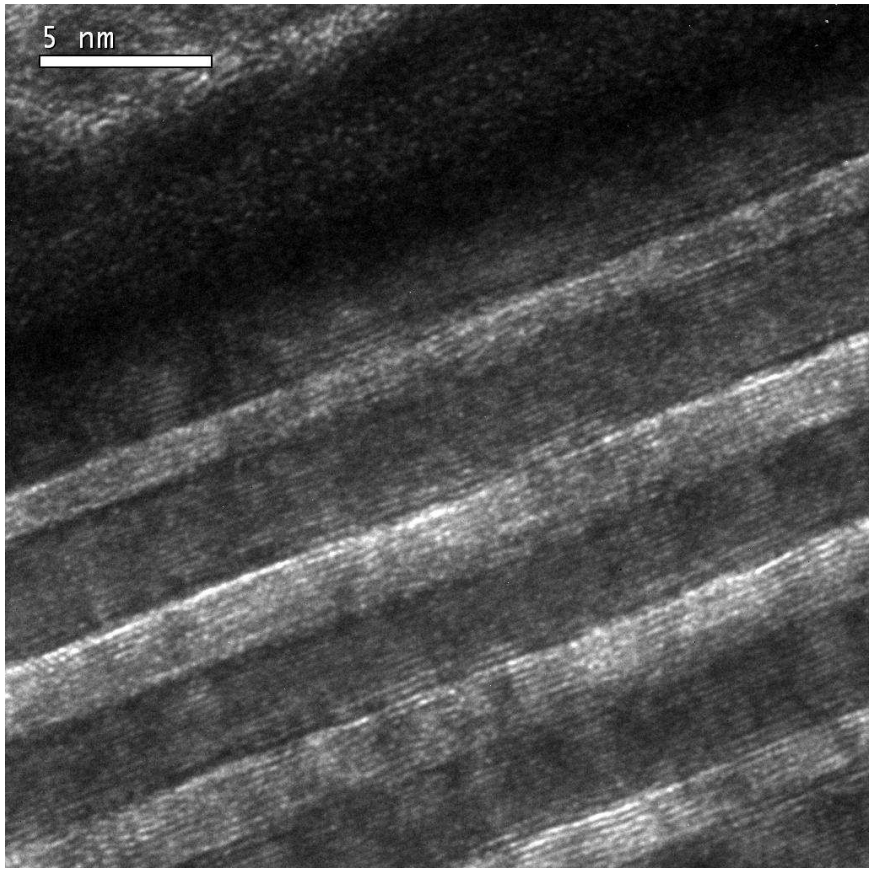
HRTEM

Etching Regime versus Soft Regime : CoFeB crystallization

Soft Energy Transfer Regime

Deposition Gun : +600V; +74mA; 4.0 sccm Xe

Assist Gun : +30V/-850V; +100mA; 10sccmAr

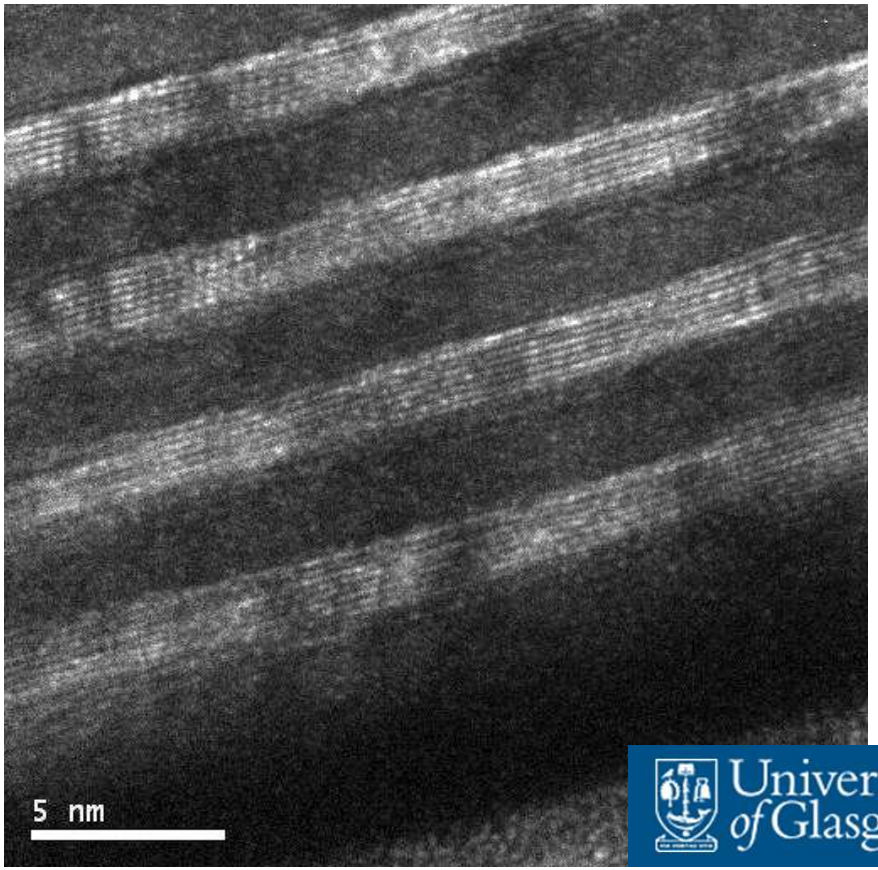


Mostly crystalline CoFeB

Concurrent Etching Regime

Deposition Gun :+800V; +108mA; 4.0 sccm Xe

Assist Gun :+275V/-175V; +70mA; 10sccmAr



Mostly amorphous CoFeB

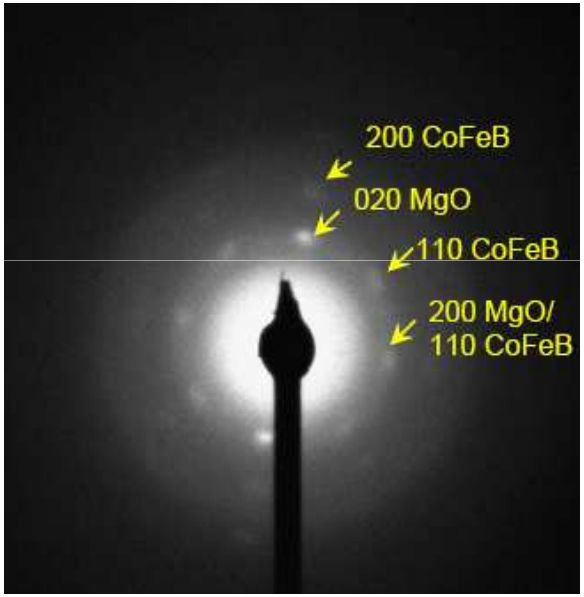
HRTEM

Etching Regime versus Soft Regime : CoFeB crystallization

Soft Energy Transfer Regime

Deposition Gun : +600V; +74mA; 4.0 sccm Xe

Assist Gun : +30V/-850V; +100mA; 10sccmAr

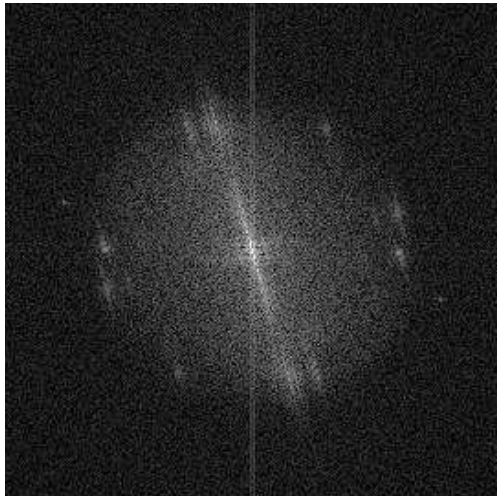


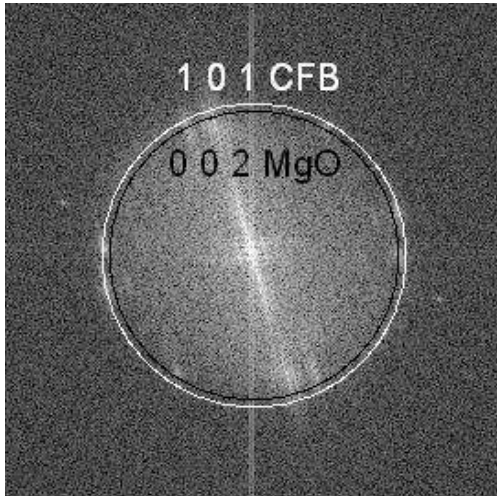
Selected Area Diffraction Pattern (SAD) shows strong out of plane [001] texture in all CoFeB and MgO layers

Concurrent Etching Regime

Deposition Gun :+800V; +108mA; 4.0 sccm Xe

Assist Gun :+275V/-175V; +70mA; 10sccmAr





- Indexed reflections in the FFT suggest [001] texture of the MgO and mixed orientations for the CoFeB
- CoFeB does not exhibit crystalline properties everywhere

Conclusions

- Ion Beam Assisted Deposition is an effective technique to obtain strong textured CoFeB/MgO
- There are two assisted deposition regimes : soft energy transfer and concurrent etching regime
- XRD data and TEM show that the crystallization of CoFeB depends strongly on the assisted deposition conditions of MgO
- Data suggests that the best conditions to obtain high textured CoFeB/MgO are obtained with high current and low voltage assistance beams

The impact of the assisted deposition conditions on the transport properties of magnetic tunnel junctions is currently being determined

Thank you for your attention!

Questions?