PhD project: Topological insulator/magnetic systems for spin-charge conversion

Journée annuelle du LabEx NanoSaclay
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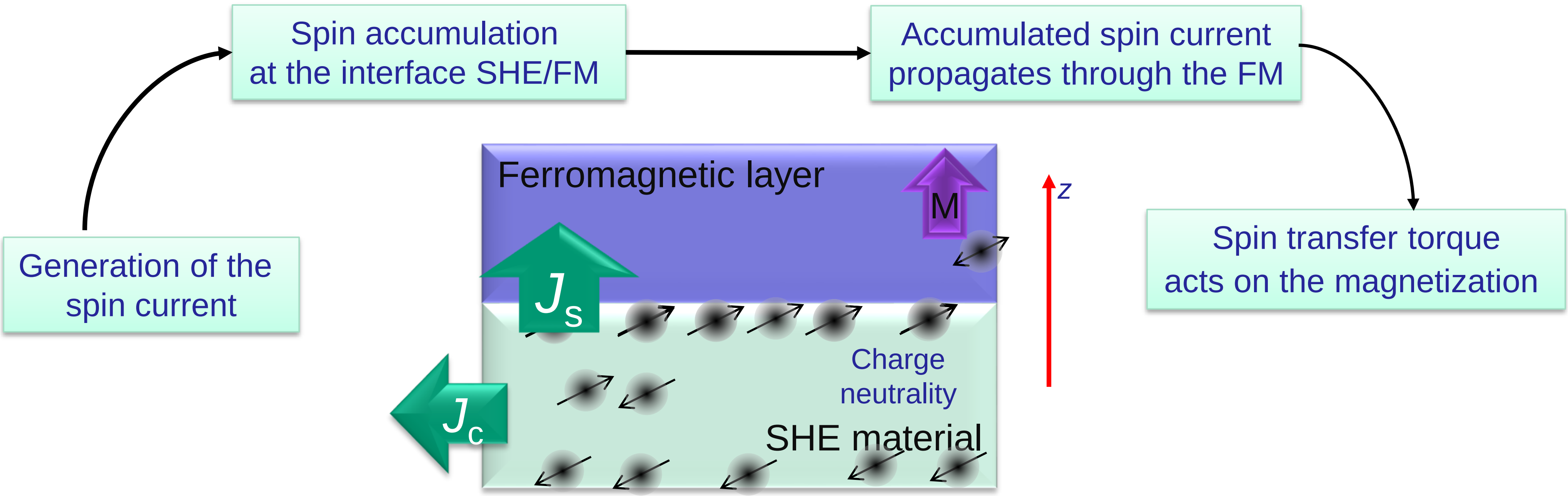
SPICY
SPIn in nanosaClaY

CNRS THALES C2N SOLEIL SYNCHROTRON UNIVERSITE PARIS-SACLAY LPENS NanoSaclay

Why generate spin current?

For magnetization manipulation!

Using spin-charge conversion (Spin Hall Effect (SHE))



BUT!

Large current densities are necessary ($\sim 10^{11} \mathrm{A/m^{-2}}$) to reverse the magnetization

Possible solution:

Using surface states of TIs allows to reduce current densities

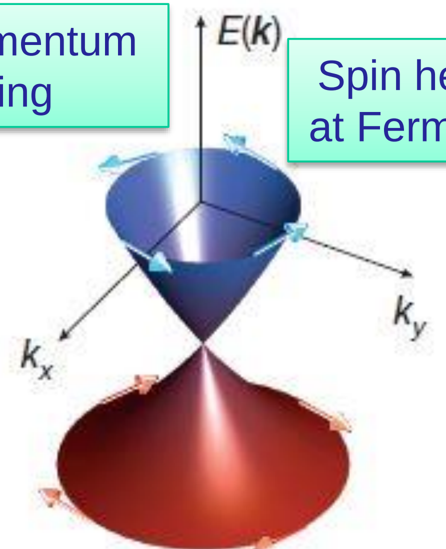
Spin-charge conversion in topological insulators (TI)

Topological surface states

Large spin-orbit coupling

Spin-momentum locking

Spin helicity at Fermi level



Dirac cone linear dispersion

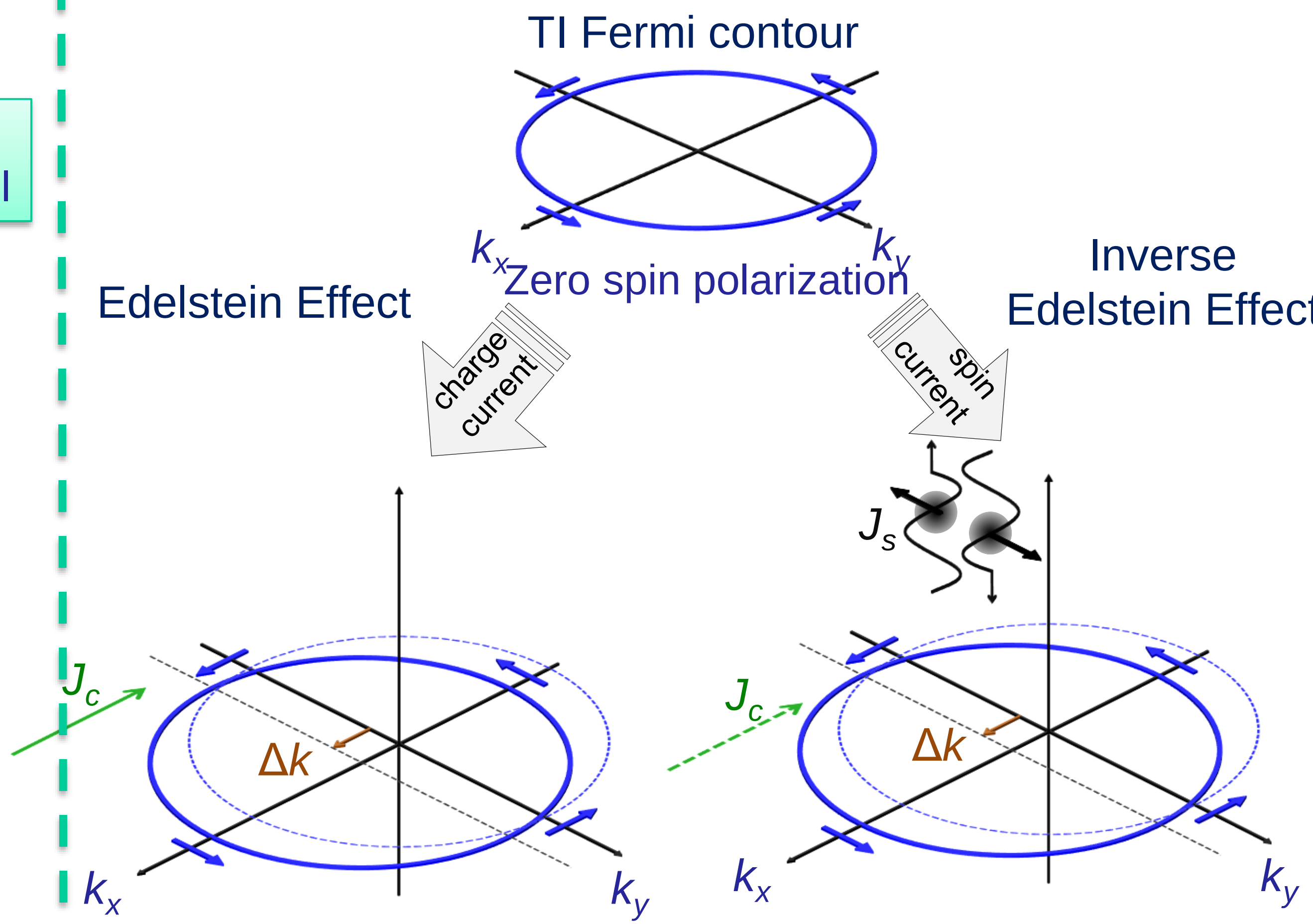
Dirac's Hamiltonian:

$$H_{\mathrm{TI}} = \hbar v_{\mathrm{F}} \left(\vec{z} \times \vec{k}\right) \cdot \vec{\sigma}$$

A. Soumyanarayanan, N. Reyren, A.Fert, C. Panagopoulos, Nature 539, 509-517 (2016)

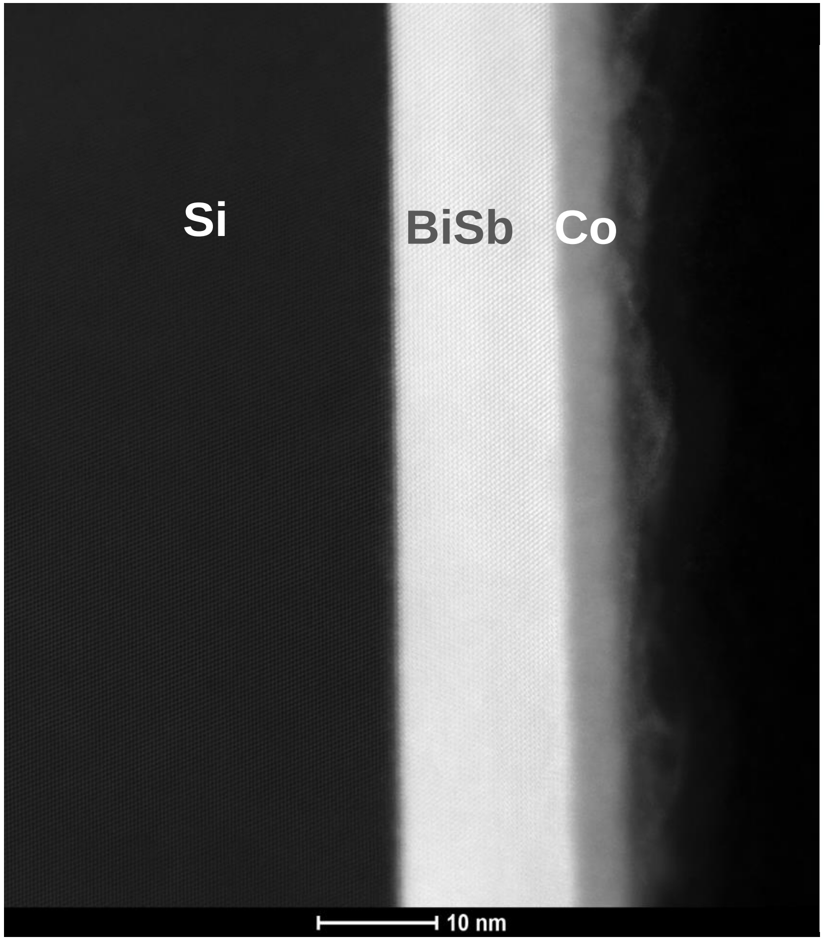
Edelstein effect and Inverse Edelstein effect

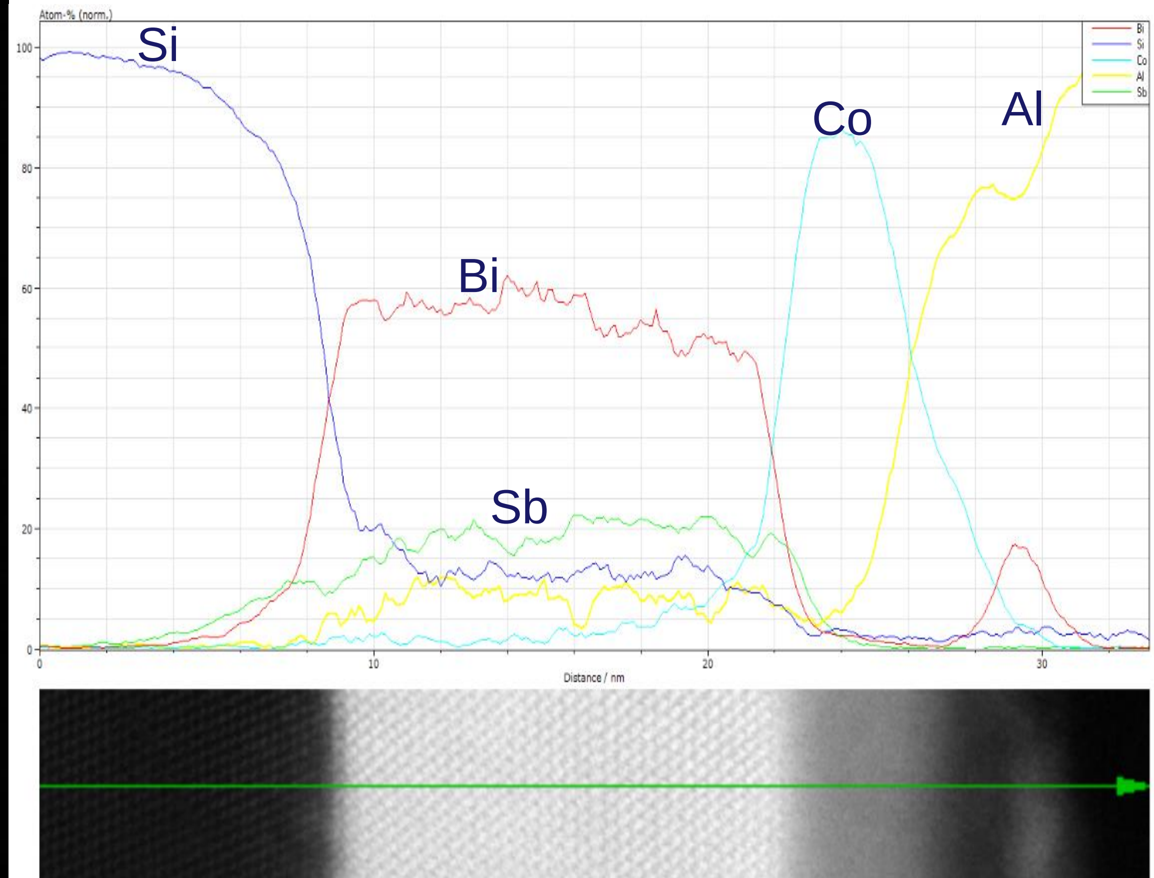
TIs: efficient spin-charge conversion



S. Zhang and A. Fert, *Phys. Rev. B* **94**, 184423 (2016)

$Bi_{1-x}Sb_x$: Topological insulator (PhD Laetitia Baringthon)



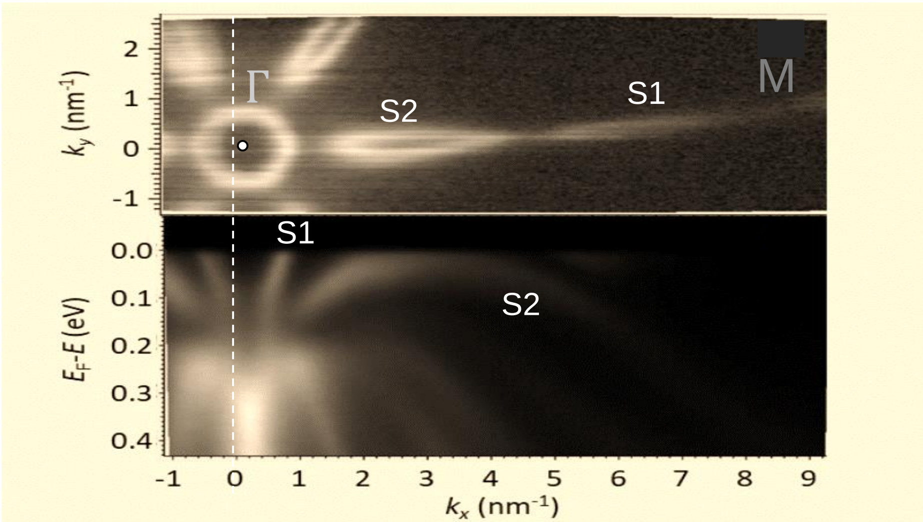


STEM-HAADF, C2N

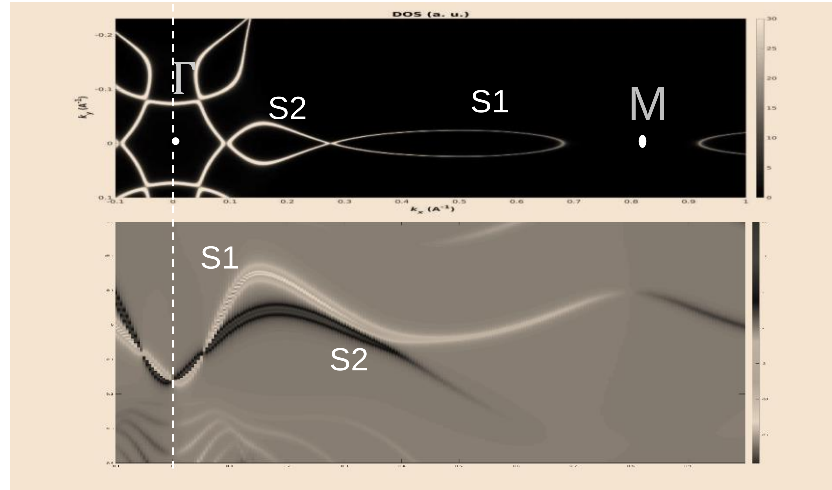
Smooth interface TI/FM

$Bi_{1-x}Sb_x$: Topological surface states (PhD Laetitia Baringthon)

ARPES measurements



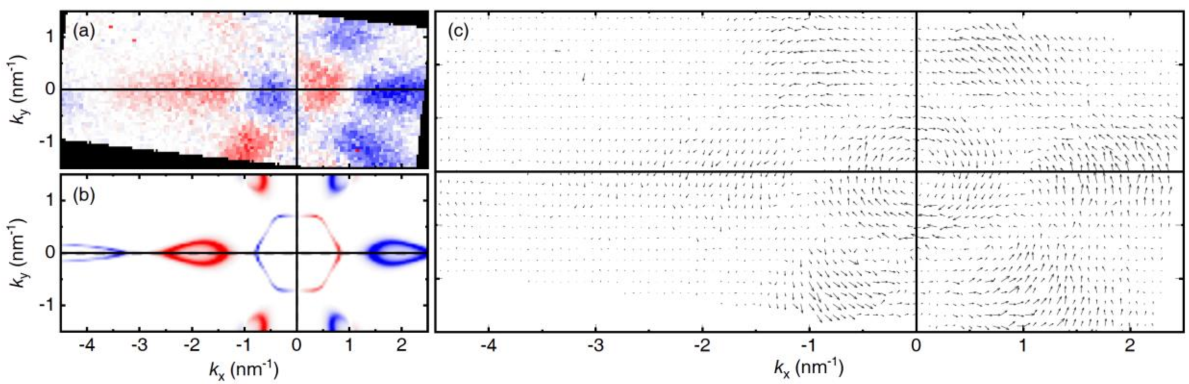
Tight-binding calculations



Presence of topological surface states

SARPES

Tight-binding calculations

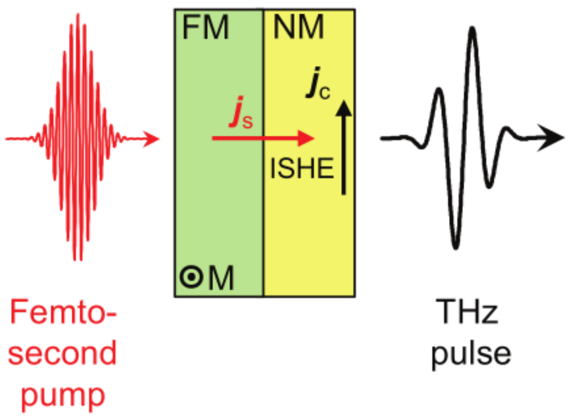


Spin texture at Fermi level

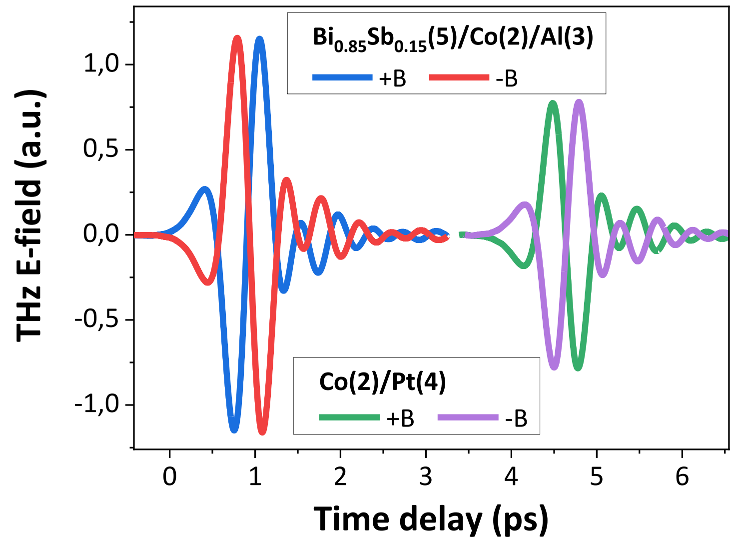
$Bi_{1-x}Sb_x$: Spin-charge conversion (PhD Laetitia Baringthon & Enzo Rongione)

THz measurements

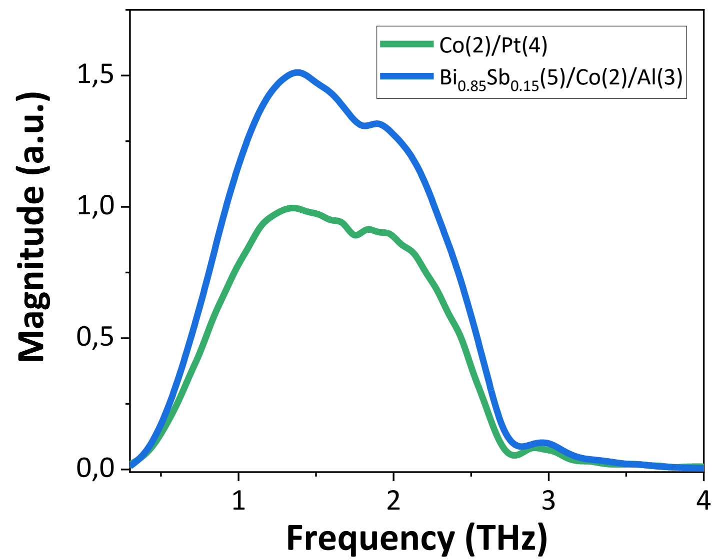
Scheme of working principle



Time domain



Spectral domain



Efficient spin to charge conversion in BiSb/Co

BUT to qualify charge to spin conversion (magnetotransport measurements e.g. spin-orbit torque), **FM layer with perpendicular magnetization** is preferable

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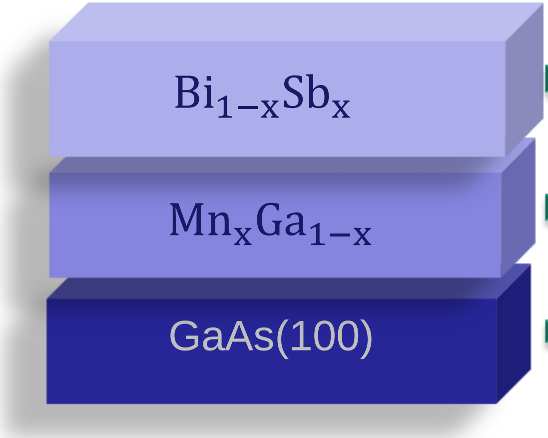
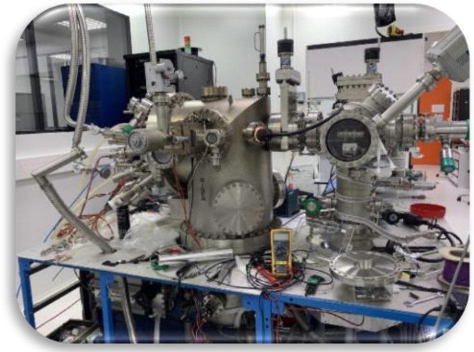
Growth by MBE (Molecular Beam Epitaxy) at C2N

Heterostructure to develop:

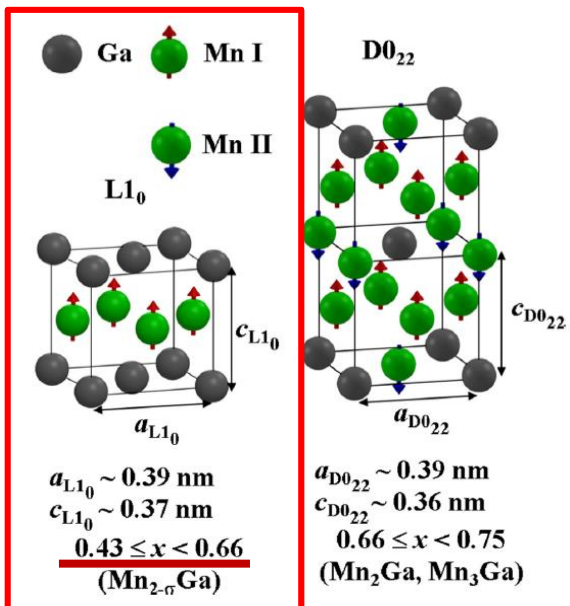


- $Bi_{1-x}Sb_x$ → Topological insulator
- Mn_xGa_{1-x} → Ferromagnet w/ perpendicular magnetization
- GaAs(100) → Resistive semi-conductor



MBE Riber R2300

Phases of MnGa depending on Mn concentration

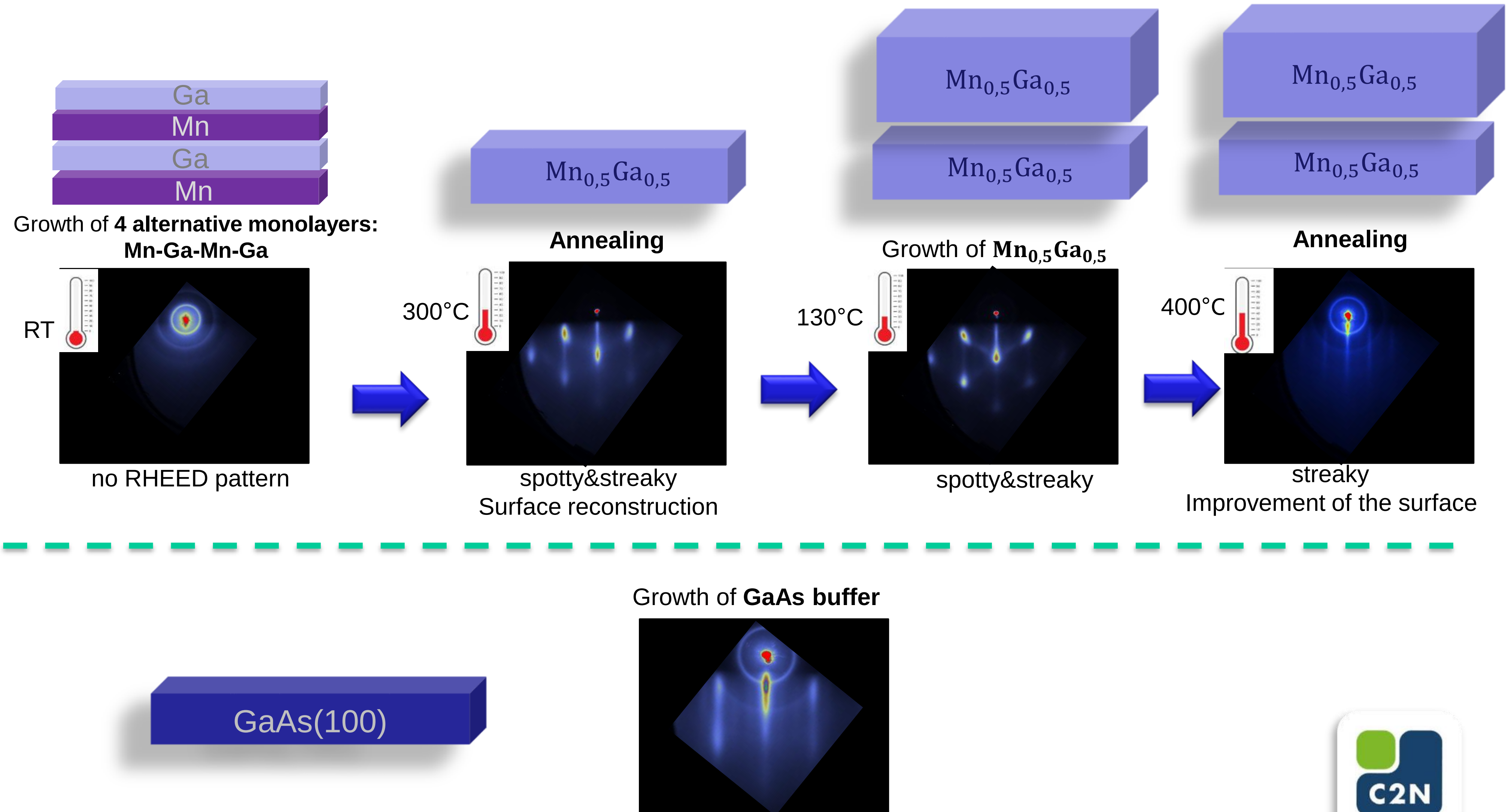


Ferromagnetic Antiferromagnetic

Duy Khang et al. , Journ.of Appl. Phys. 122, 143903 (2017)

Growth of MnGa by MBE (Molecular Beam Epitaxy)

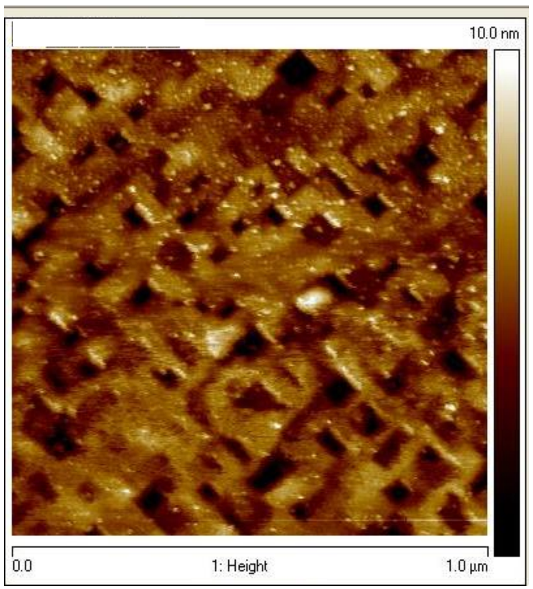
Growth procedure:



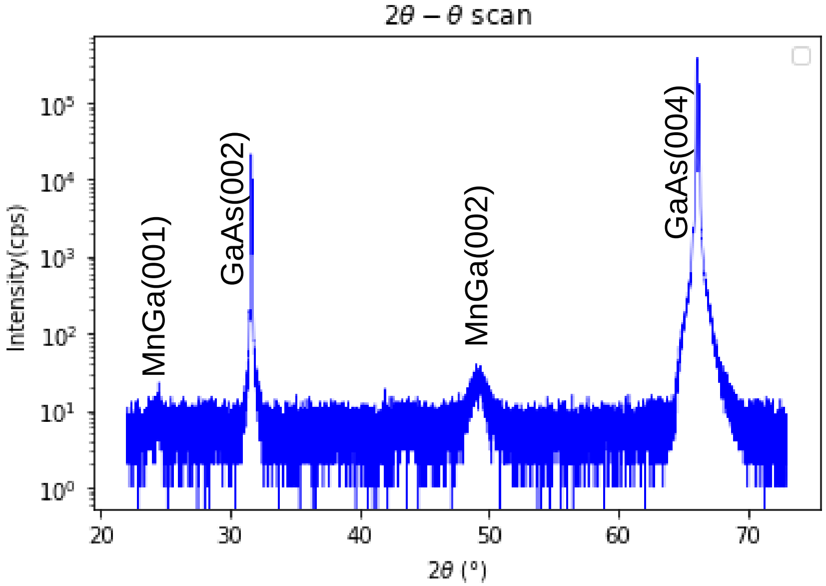
C2N

Characterization of structural properties of MnGa

AFM image: MnGa surface



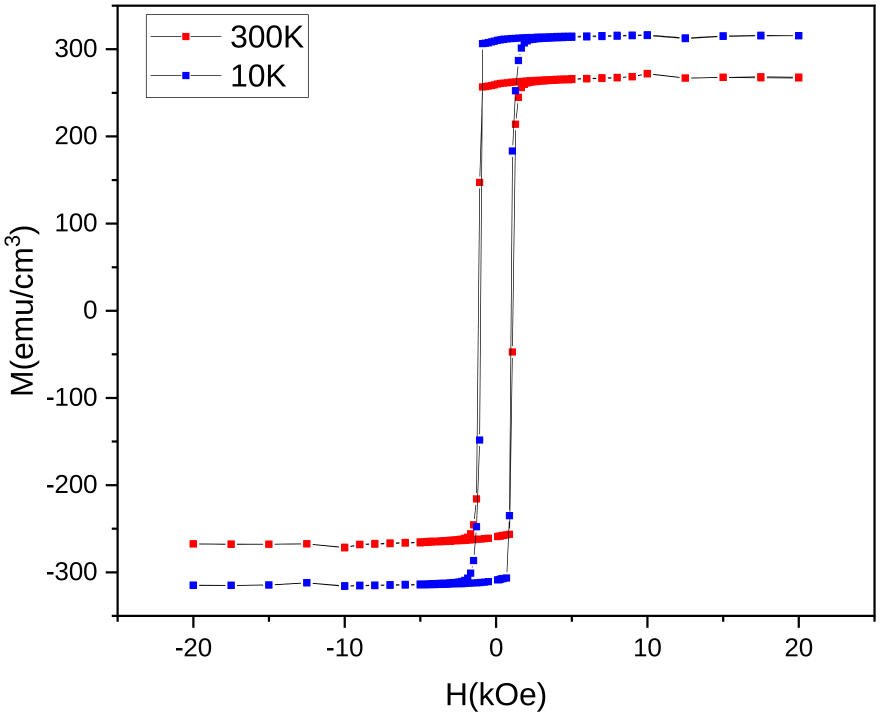
Steps, flat surface



Growth of MnGa on GaAs(100) with (001) crystallographic orientation is confirmed

Magnetic properties of MnGa

SQUID (superconducting quantum interference device) measurements: field applied out of plane



10K:

$M_s = 315\ \mathrm{emu/cm^3}$

μ=0,48 μ_B/atom

H_c=1kOe

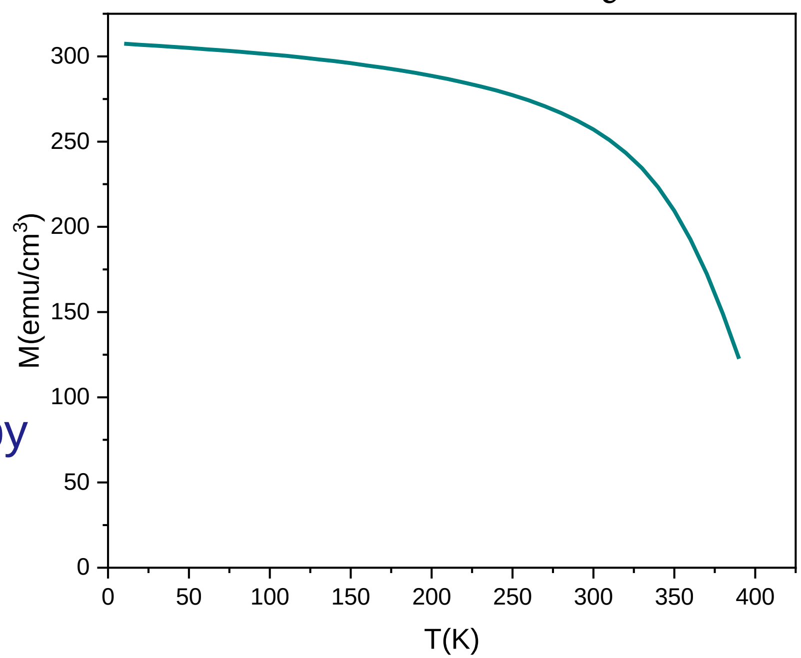
300K:

$M_s = 267\ \mathrm{emu/cm^3}$

μ=0,41 μ_B/atom

H_c= 1kOe

$T_c > RT$



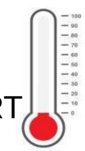
MnGa exibits desirable perpendicular magnetic anisotropy and high Curie temperature

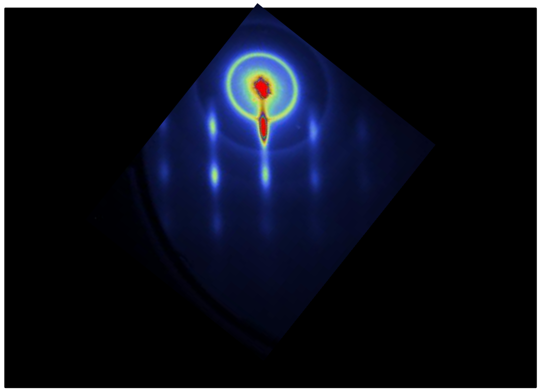
Growth of BiSb by MBE (Molecular Beam Epitaxy)

$Bi_{0,85}Sb_{0,15}(9nm)$

Growth of $\mathbf{Bi_{0,85}Sb_{0,15}}$

RT

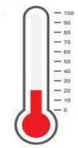


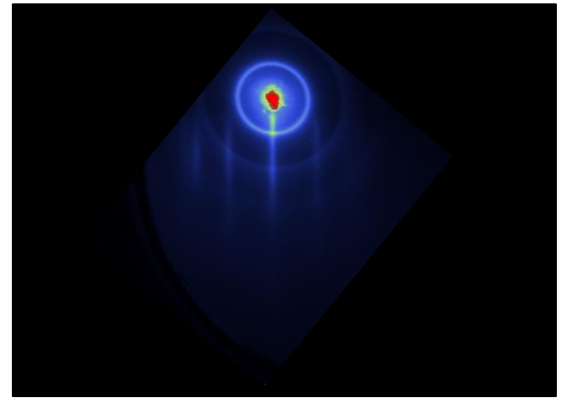


spotty&streaky

Annealing

180°C



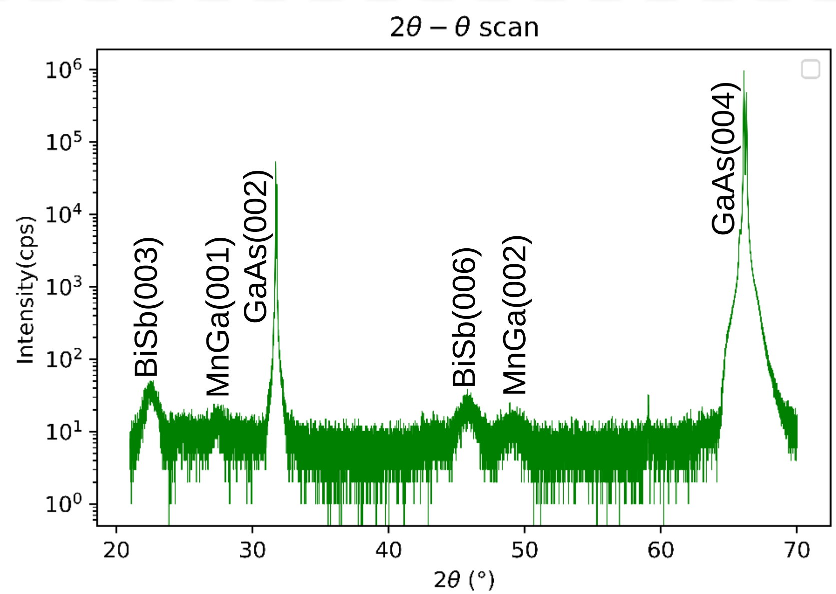


streaky

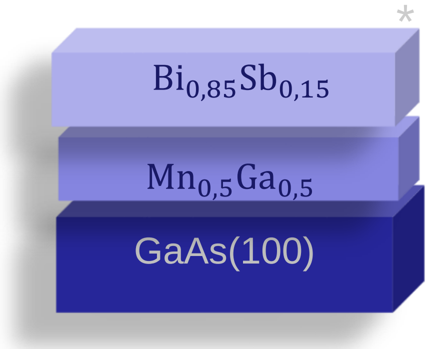
Improvement of the surface

BiSb/MnGa system on GaAs(100)

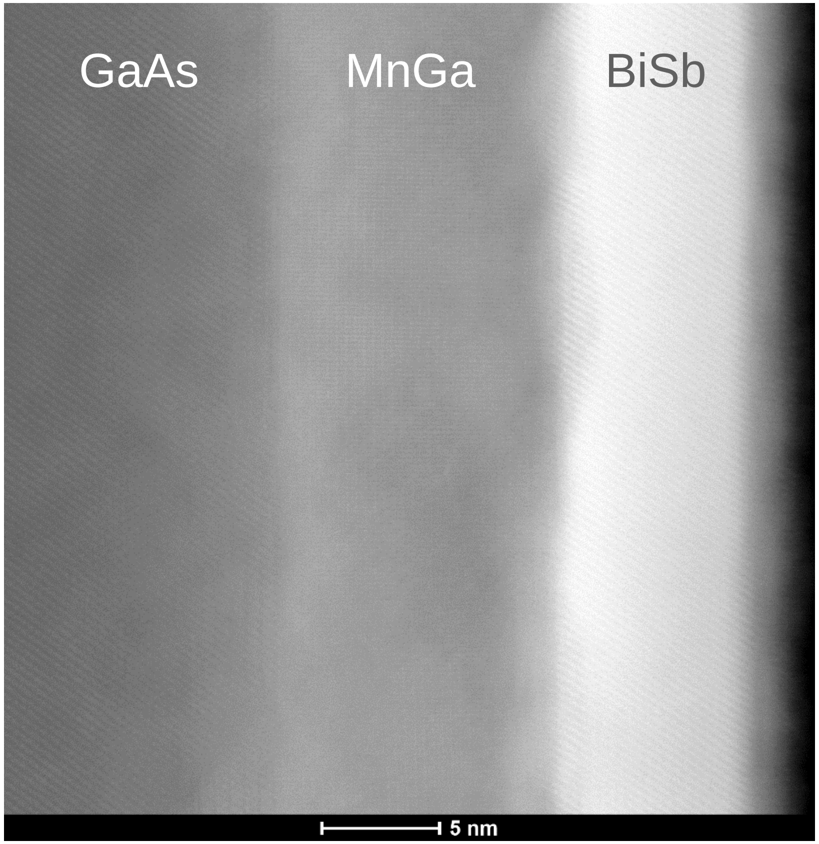
XRD shows (003) crystallographic orientation of BiSb



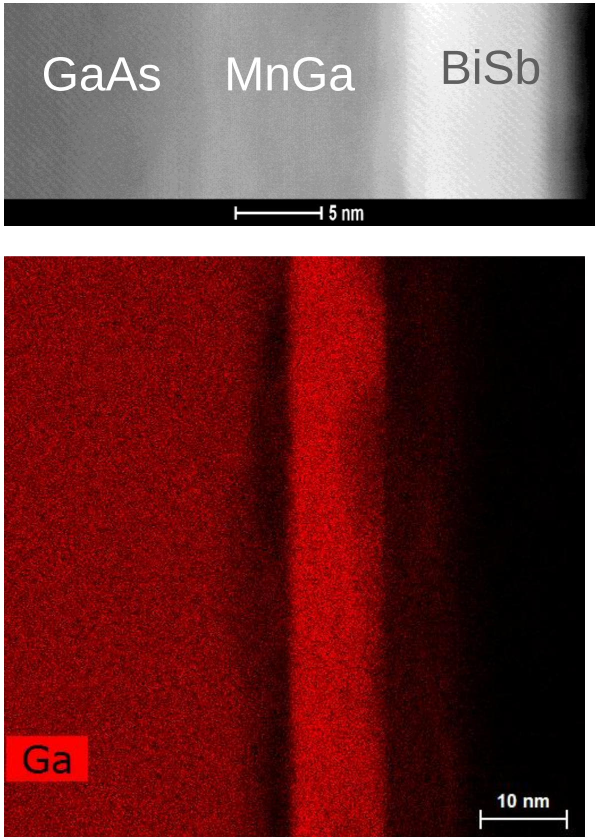
Characterization of structural properties of BiSb/MnGa/GaAs(100)



*Not on scale



STEM-HAADF, C2N



EDX map of Ga, C2N

Conclusions and perspectives

What has been done:

- Bi-dimensional growth of MnGa layers with flat surface
- Desirable magnetic properties of MnGa layers have been achieved
- Growth of BiSb on top of MnGa with (003) crystallographic orientation

What's next:

- Analysis of ARPES data acquired at Synchrotron SOLEIL
- Charge to spin current conversion (magnetostransport measurements, e.g. spin-orbit torque, magnetization switching) of BiSb/MnGa system