Lattice site location of implanted Fe in $SrTiO_3$ and lattice damage recovery studies

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WORKSHOP AND USERS
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Outline

Materials,

- Undoped $SrTiO_3$
- $SrTiO_3$ pre-implanted with stable Fe

emission channeling technique,

studies

- Fe lattice site location
- lattice damage recovery
- Magnetic properties
- impurities search by means of PIXE

and conclusions.

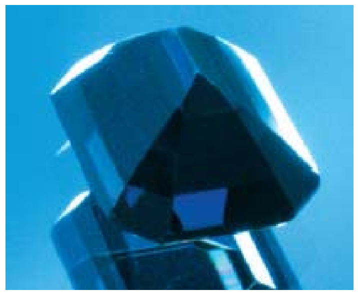
Why studying $SrTiO_3$?

Because …

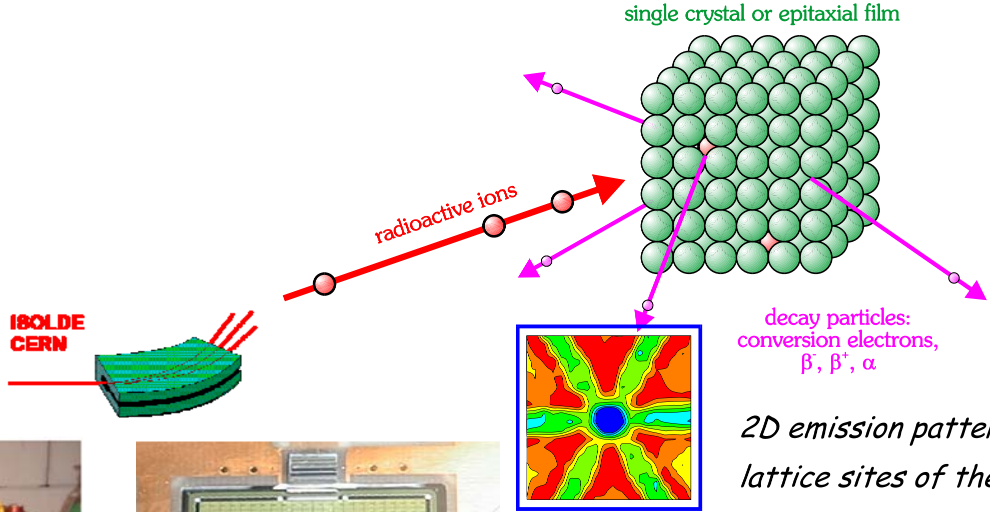
- **High bulk dielectric constant** → microelectronic applications (ex. high-k FET).
- **interesting and complex electrical, optical and magnetic properties** that can be modified by the incorporation of dopants → (**ex. Fe-doped $SrTiO_3$** has been applied in **electrochemical electrodes and resistive oxygen sensors**)
- **Transition metal doped $SrTiO_3$ is a possible material for a RT ferromagnetic semiconductor → Spintronics applications**
- **Variety of phase transitions in the low temperature range**

Besides,

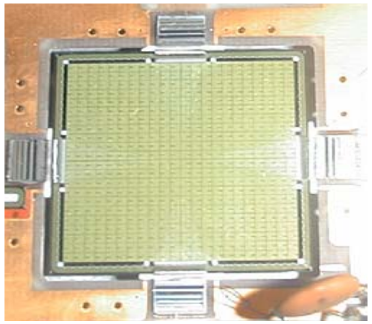
- **little is known on the lattice site location of implanted impurities and remaining point defects in heir neighborhood.** → EC and PAC can give unique answers in that respect!

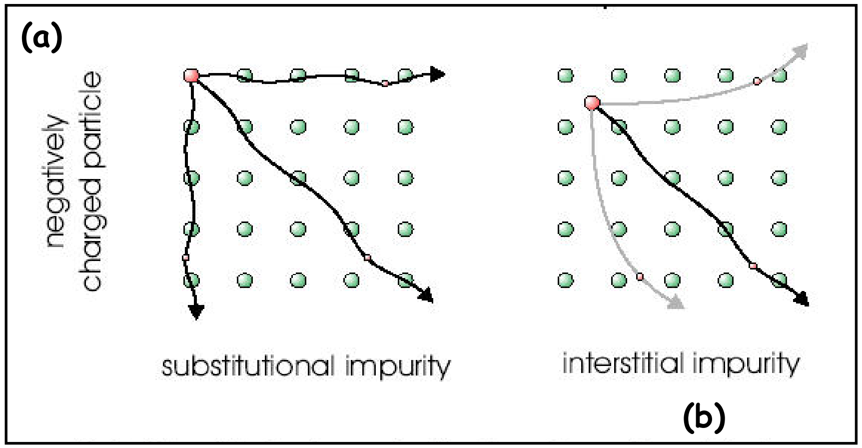


Electron Emission Channeling



2D emission patterns characterizes specific lattice sites of the emitting atoms (accuracy up to 0.1 Å)



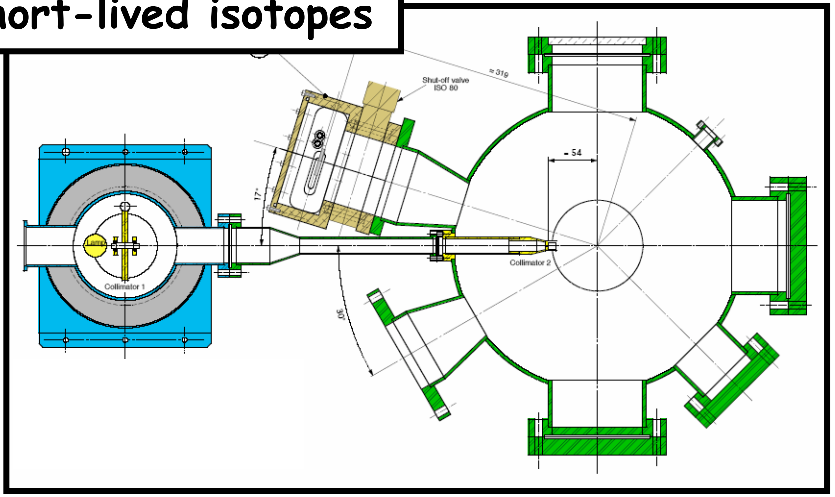


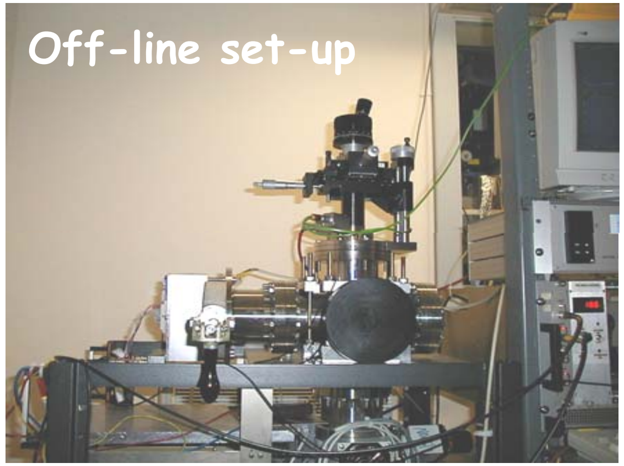
(a) *When electrons are emitted from substitutional impurities, there will be a* ***channeling effect****: electrons ere preferentially steered along this row of atoms, resulting in a higher anisotropy.*

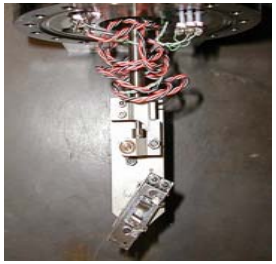
(b) *When electrons are emitted from interstitial impurities there will be* ***channeling and blocking effects*** *that will decrease the anisotropy when looking along the row of atoms.*

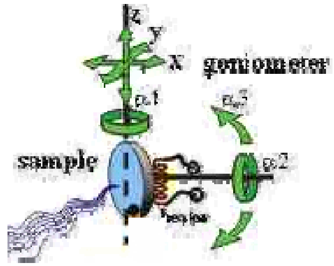
Experimental set-up

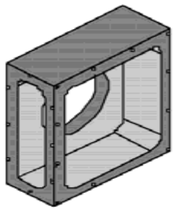
On-line set-up for short-lived isotopes

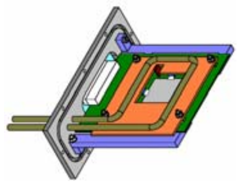












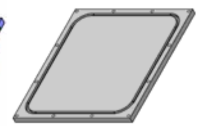
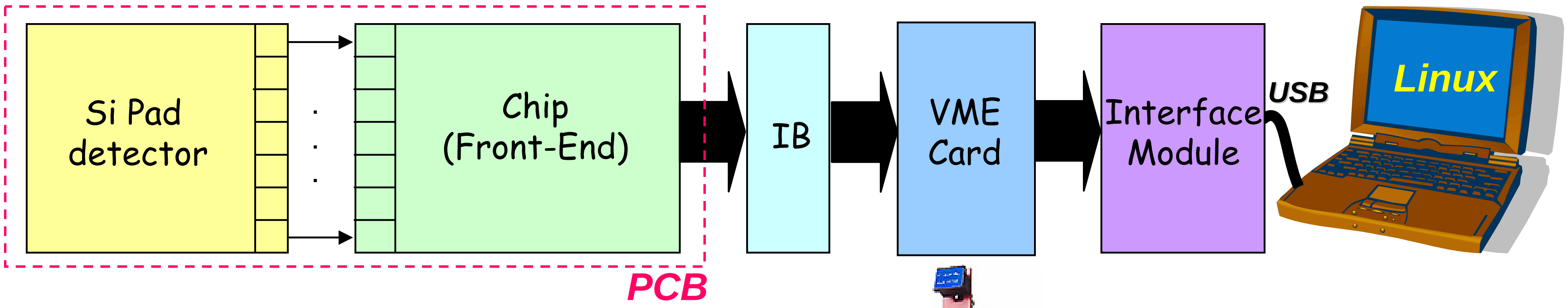
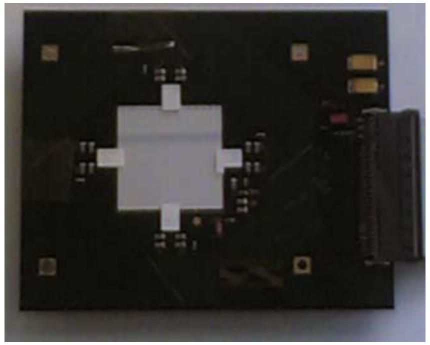


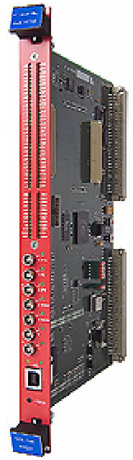
Table: Some radioactive isotopes for possible future use with the EC technique:

	radioisotope	parent	half-life	decay ratio (%)	E (keV)
low energy conversion Electron emitters	^{73}Ge	^{73}As	80.3 days	181	10-53
	^{119}Sn	^{119m}Sn	293.1 d	192	19-66
	^{125}Te	^{125}I	60.1 d	33.3	22-35
	^{58}Co	^{58m}Co	9.15h	92.6	17.2-24.1
	radioisotope	**parent**	**half-life**	**E (keV)**	**E_{max} (keV)**
short-lived β^- emitters	^{27}Mg	^{27}Na	9.5 min	703	1767
	^{61}Co	^{61}Fe	1.7 h	460	1254
	^{65}Ni	^{65}Co	2.5 h	629	2137
	^{69}Zn	^{69}Cu	56 min	322	906
	^{75}Ge	^{75}Ga	1.4h	421	1177

VATA-DAQ as a readout system







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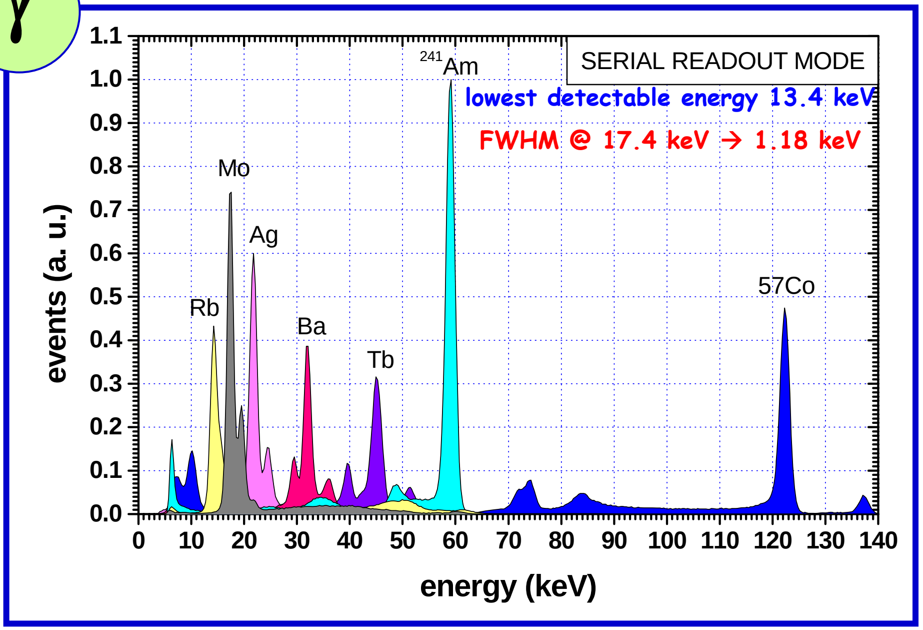
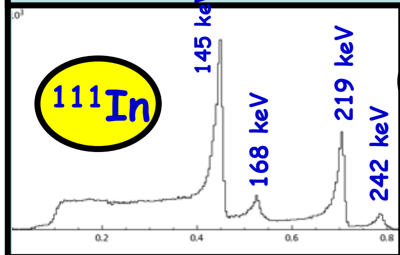
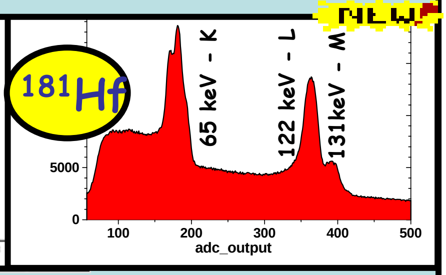
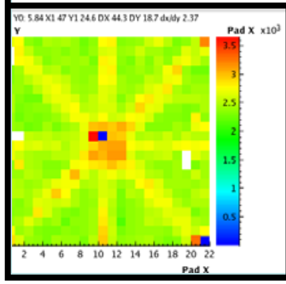


e⁻

INTEGRAL SPECTRA - NOT GAIN CALIBRATED







- Lowest ^{111}In electron energy of 145 keV has an FWHM of 4.8 keV!
- Lowest energy that can be detected with this PSD is 15 KeV!

EC results – $^{59}Fe:SrTiO_3$

Undoped sample ion implantation details

Where: ISOLDE, CERN (Geneva)

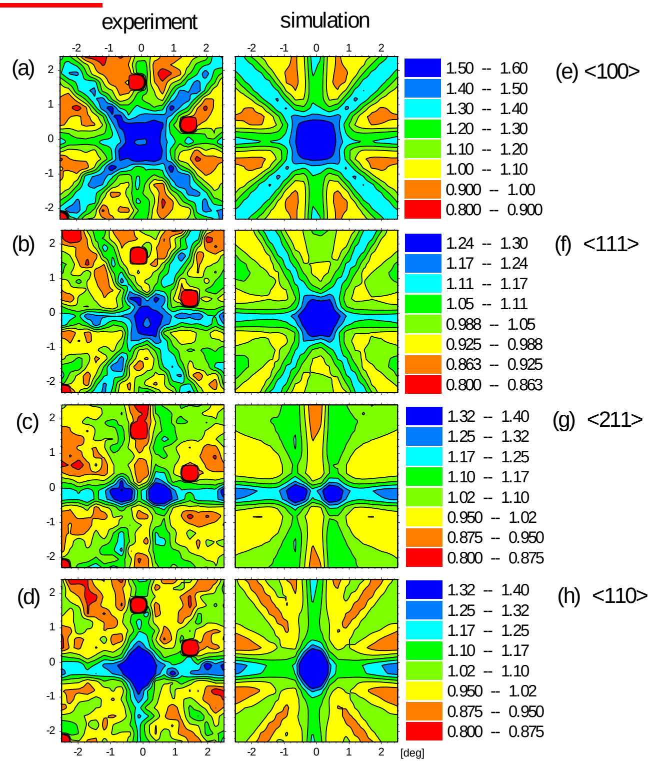
Energy: 60 keV

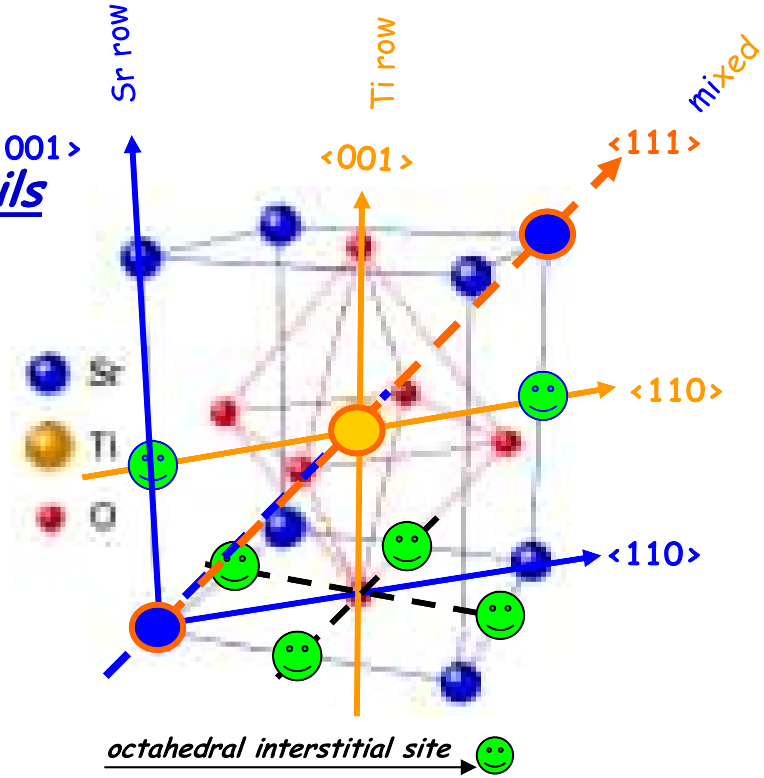
Dose: 2×10^{13} at./cm^2

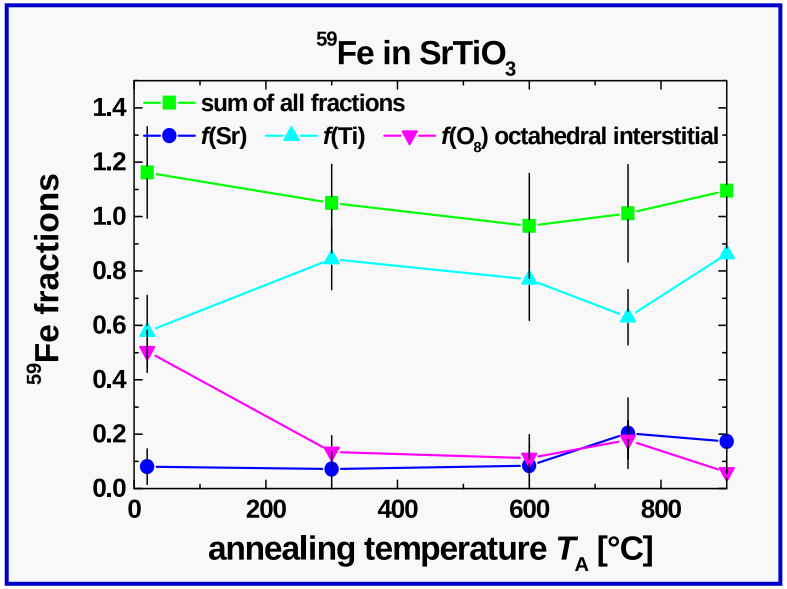
EC measurements: patterns were recorded along 4 directions in the as-implanted state and after annealing at 300°C, 600°C, 750°C and 900°C.

Results

Angular distributions "@" 900°C



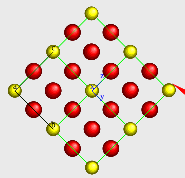




$SrTiO_3$ lattice characterization by RBS/Channeling

Crystalline directions under study:

<100>



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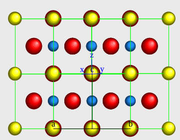

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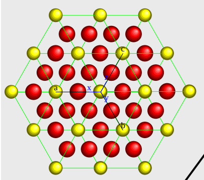


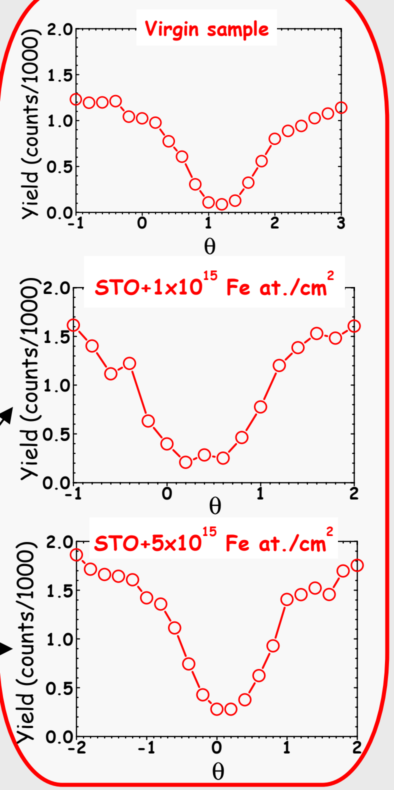
After 900°C annealing

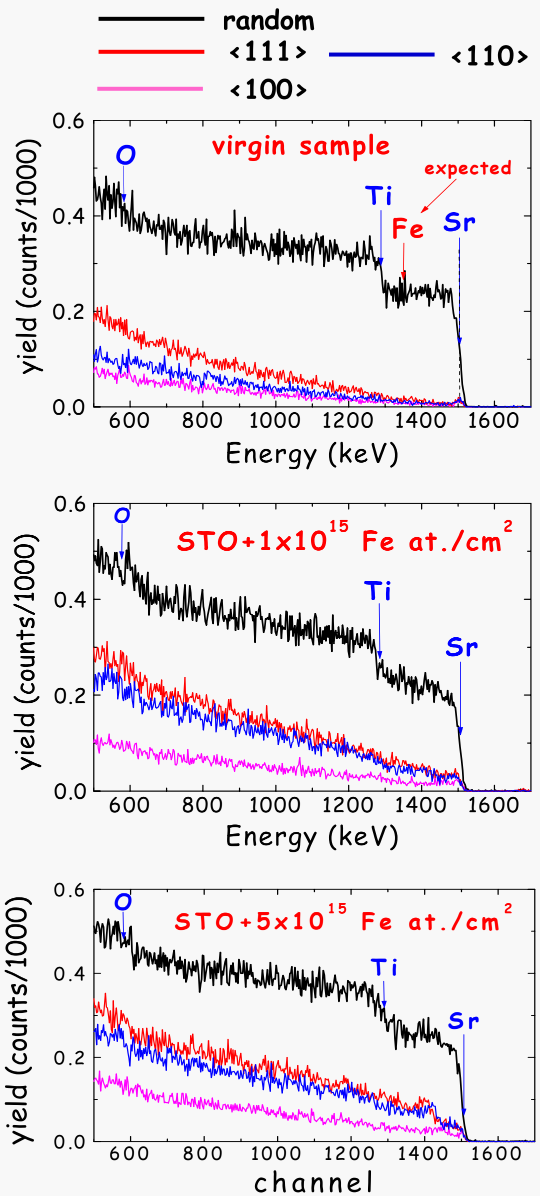
Crystalline quality for <100>:

Virgin samp. → 1.9%

STO+1x10^{15} Fe at.cm^2 → 8.5%

STO+5x10^{15} Fe at.cm^2 → 9%





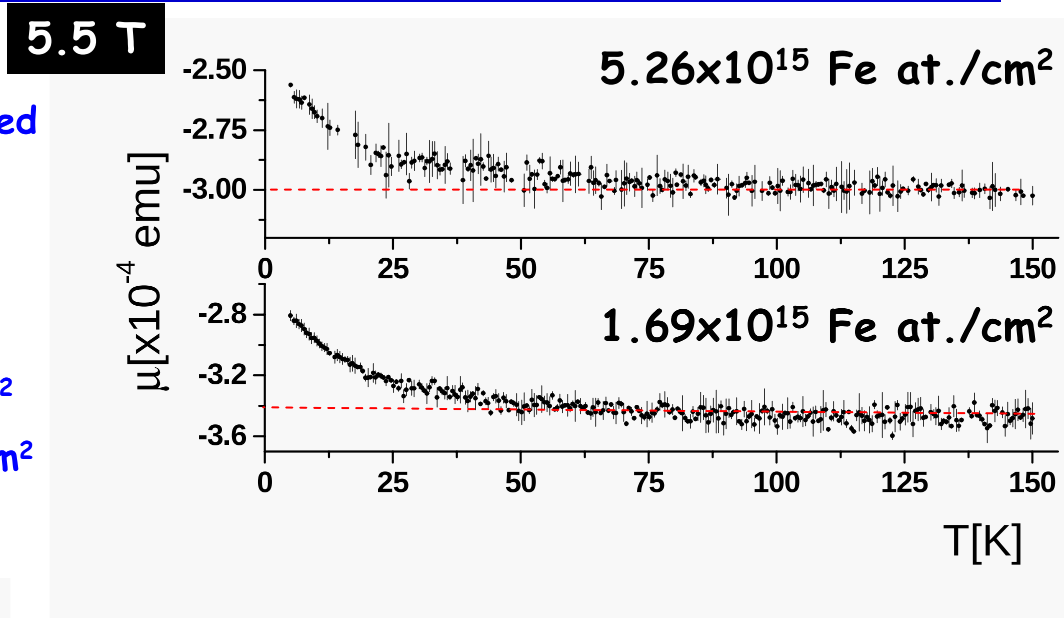
Magnetic measurements performed with a SQUID

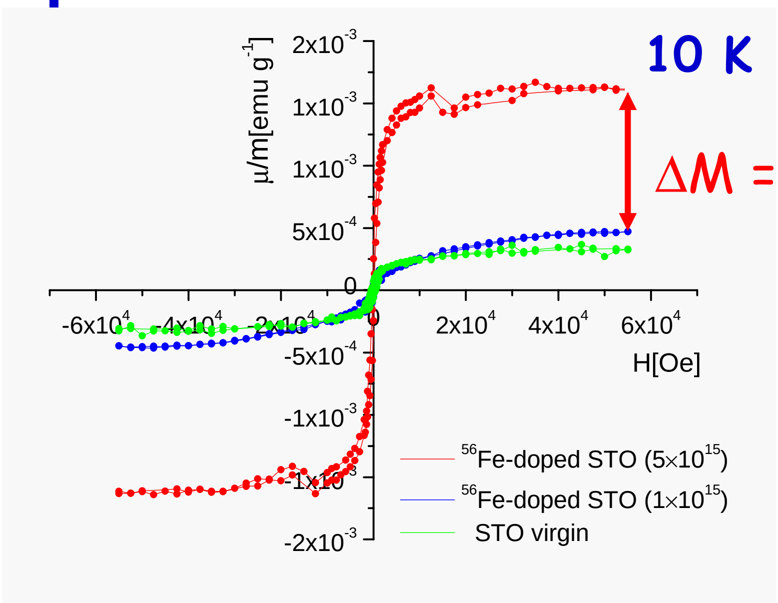
Automated control of temperature, magnetic field and helium liquefaction

Magnetic measurements performed with a SQUID

Magnetic measurements were performed in two $SrTiO_3$ samples pre-implanted with stable Fe at ITN-Portugal and after 900°C vacuum annealing.

Low dose sample → 1.69×10^{15} at./cm^2
High dose sample → 5.26×10^{15} at./cm^2
Undoped sample as sensitized





$\Delta M = 8,8\ \mu_B/Fe$

Fe	→ 2.2 μ_B
Fe^{2+}	→ 6 μ_B
Fe^{3+}	→ 5 μ_B

ΔM is considerably higher!!

Why?? … we still don't know!

⇒ μ is normalized to the mass sample

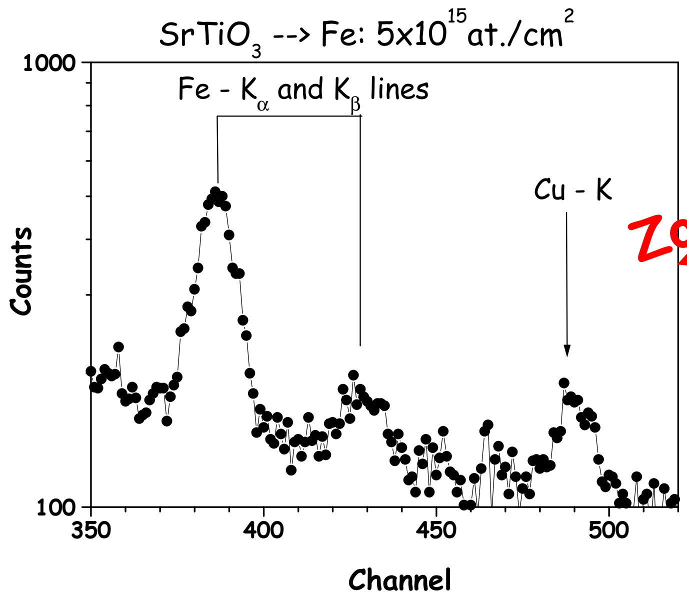
Impurities search in $SrTiO_3$ by means of PIXE

PIXE analysis revealed the following:

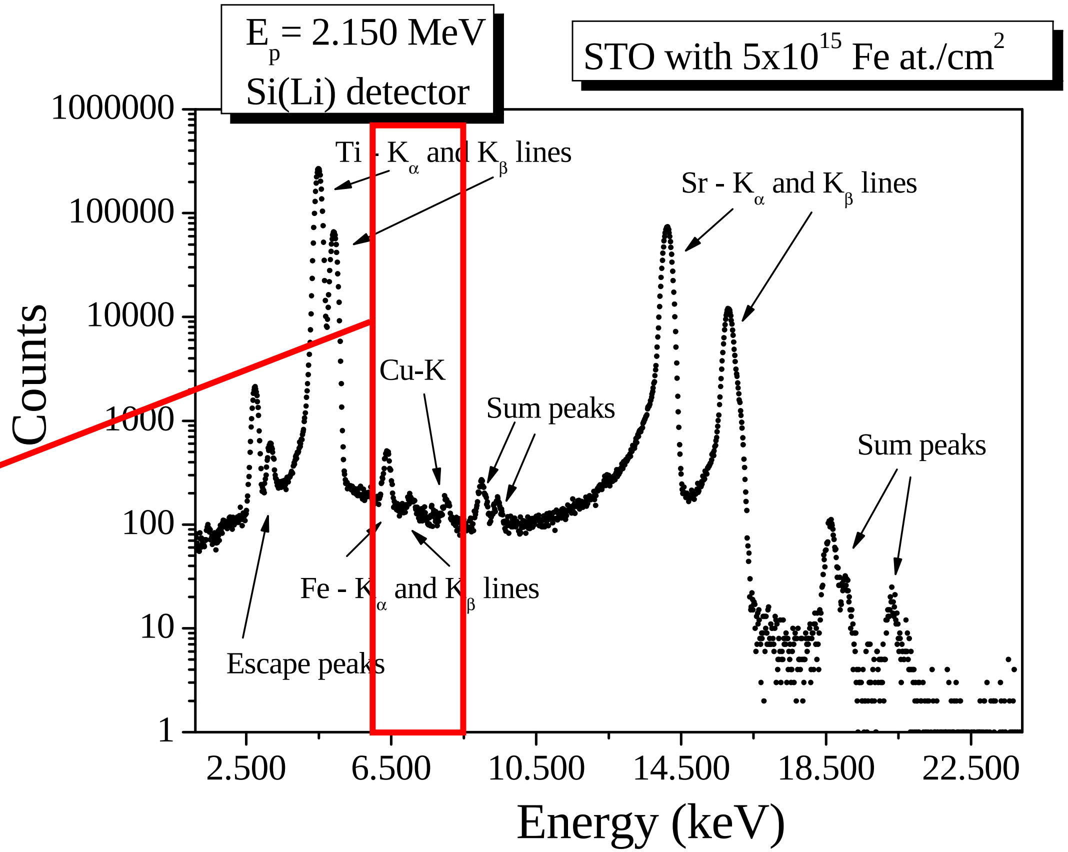
	Low dose sample	High dose sample
[Stable ^{56}Fe] (at./cm²)	1.69×10^{15}	5.26×10^{15}
[Cu impurity] (at./cm²)	2.05×10^{15}	1.99×10^{15}

Cu paramagnetic impurity
$\mu(Cu^{2+})$/ion = 1.7 μ_B

→ **Absence of Cu impurities in the Virgin sample**



Zoom



Summary / Future work

- **Emission Channeling**
  - up to 900°C ^{59}Fe atoms preferentially go to Ti-near sites (~86%).
- **RBS/Channeling Spectroscopy**
  - Good crystalline quality samples
  - after Fe-doping and 900°C post-annealing there are still remaining defects in the sample.
- **SQUID Measurements**
  - The magnetic properties are modified by the introduction of Fe dopant to different doses.
  - Magnetization increases with Fe concentration but to a value bigger than what would be expected.

Why? We still don't know but the following questions comes up:

→ What is the Fe atoms valence in the crystal?

→ Are the remaining defects playing a role? Or clusters have been formed after the annealing?

FUTURE WORK: Future work at ISOLDE will be to study ^{65}Ni (2.5 h) and ^{61}Co (1.5 h) lattice site location in $SrTiO_3$ and other oxides.