YBCO PHASE TRANSFORMATIONS STUDIED BY REAL TIME SYNCHROTRON RADIATION

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The BCS Theory: Central inherence – complex coupling between a pair of electrons of opposite spin and momentum trough an interaction with lattice phonons.

Electrons form Cooper pairs; The maximum length at which the phonon coupled attraction occur - the coherence length ξ.

Since the electron coupling is weak the energy difference (normal-superconducting state) 2Δ *is small* ($2\Delta = 3.5kT_c$) *& appears in the density of states centered about the Fermi energy at 0 K.*

When T raised the Amplitude and Frequency of atomic motion increase, interfering with the propagation of phonons between correlated Cooper pairs; The attraction between electrons is diminished and $2\Delta\downarrow$.

Any perturbation in structure/composition extending over the ξ *can alter* T_c *or* 2Δ, *placing a practical limit on useful superconducting behavior.*

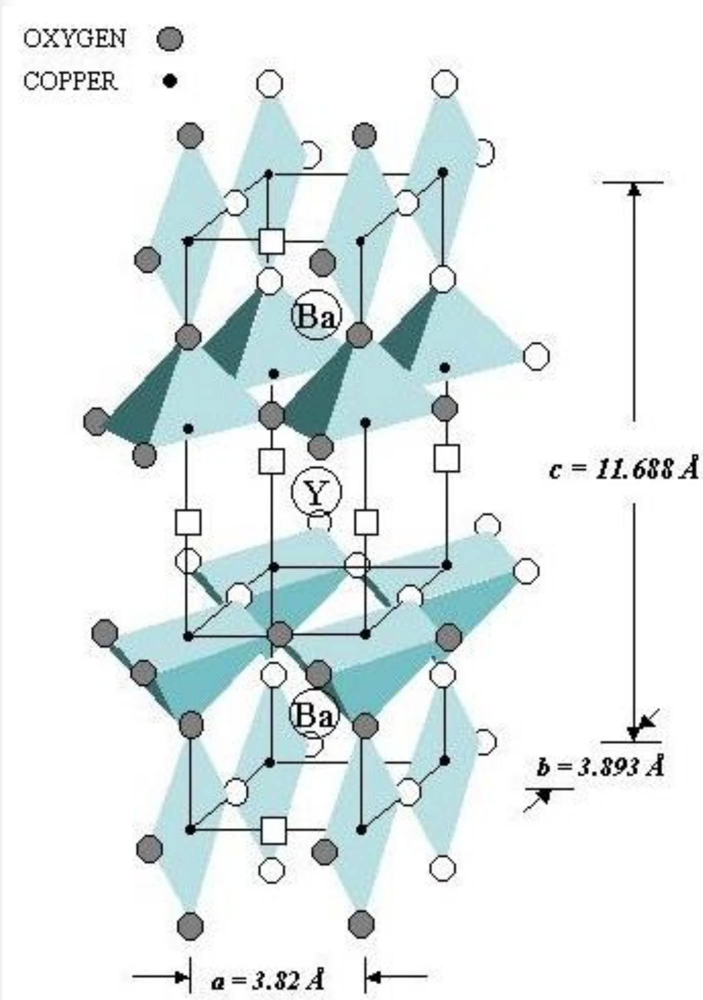
A link between T_c and the fundamental nature of the material is suggested by the BCS formula, $N(E_F)$ is the DSST at Fermi level, U-magnitude of the attractive electron-lattice interaction, γ -the lattice frequency.

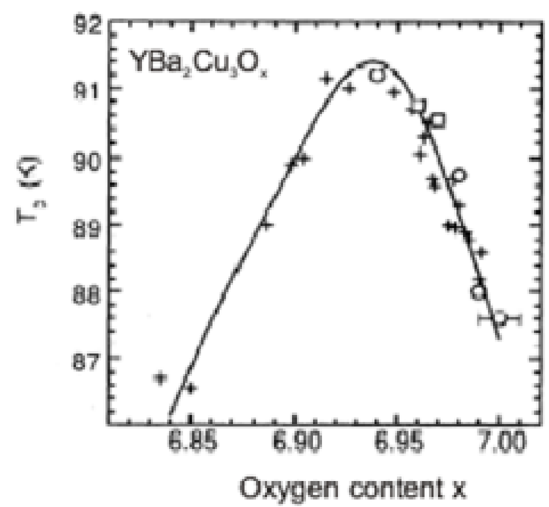
$$T_c = \frac{1.14h\gamma}{k}\exp-\frac{1}{N(E_F)U}$$

Efforts has been expended in correlating the crystal structure and oxygen content with T_c.

$$YBa_2Cu_3O_{7-\delta}$$

Oxygen affect the atom spacing and modify the valence of Cu as well as the Cu-O bond length.

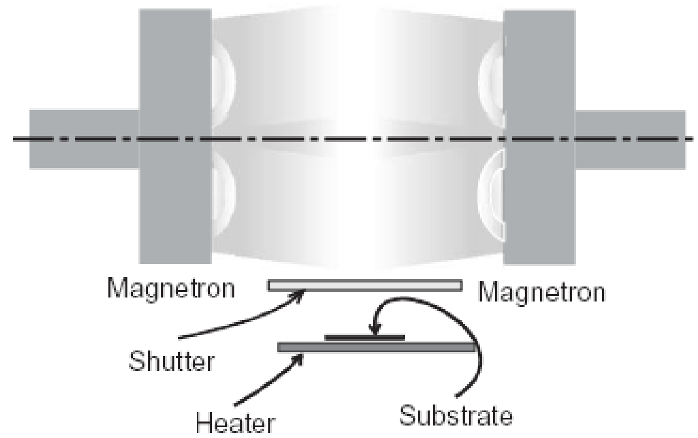




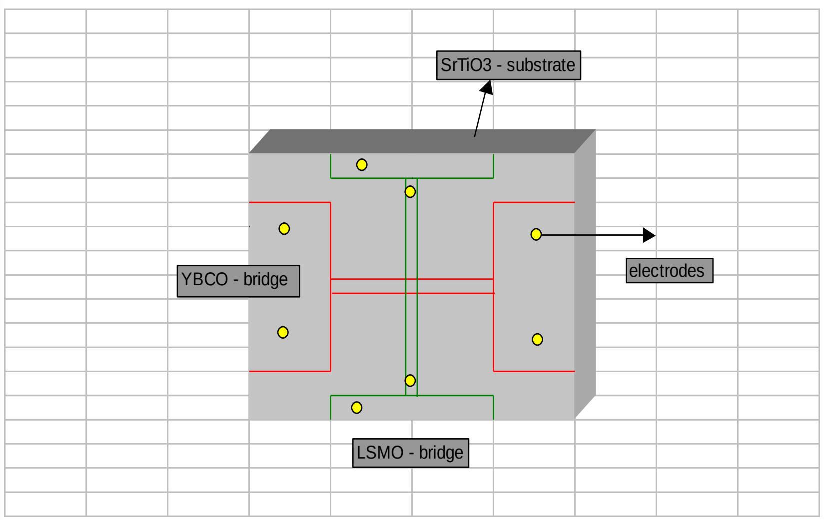
Four type structures; YBCO/STO, LSMO/STO, YBCO/LSMO/LAO and LSMO/YBCO/STO were deposited and characterized in order to solve numerous questions about the growth mechanisms, phase formation and phase interactions.

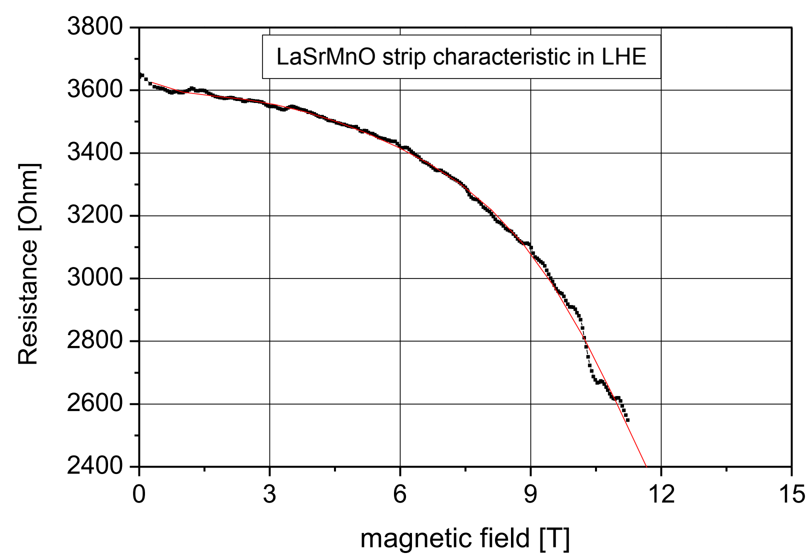
Analytical Techniques:

- XRD and Rocking curves;
- RBS in random and channeling geometry;
- Synchrotron scattering X-ray study.



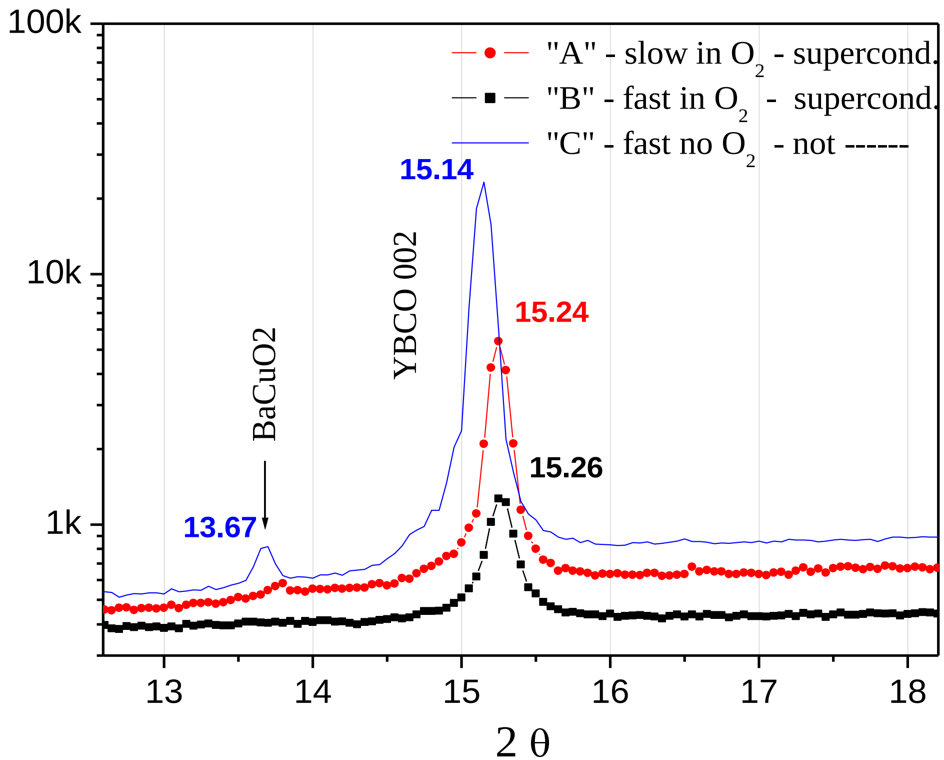
Spin-polarized electron injection device





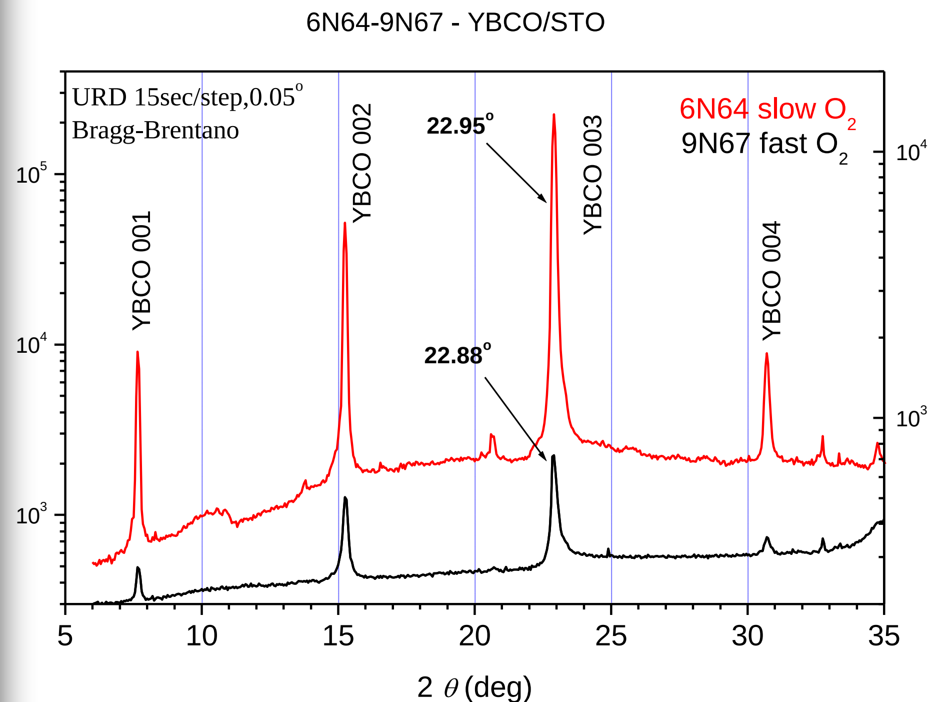
In order to study the relative oxygen content three types YBCO/STO structures were deposited by varying parameter oxygen pressure and annealing time:

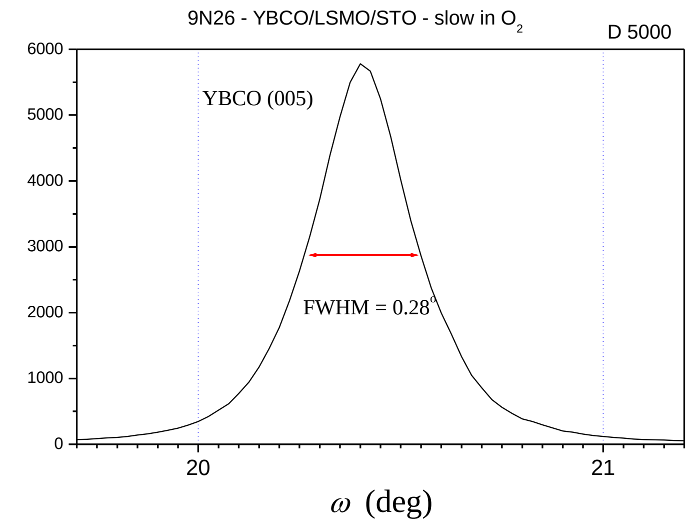
1. “Sample A” annealed slowly (1h) in oxygen pressure of 700 mbar;
2. “Sample B” annealed quickly (20 min) in the same ambient;
3. “Sample C” has been annealed without oxygen supply.

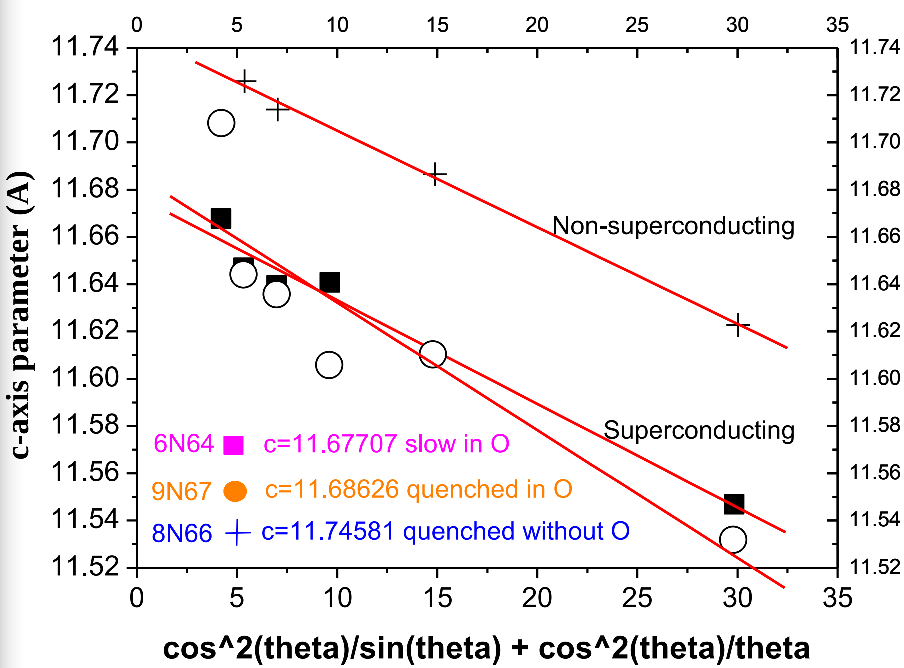


Zoomed XRD spectra of YBCO (002) peak for the three types structures -YBCO/STO

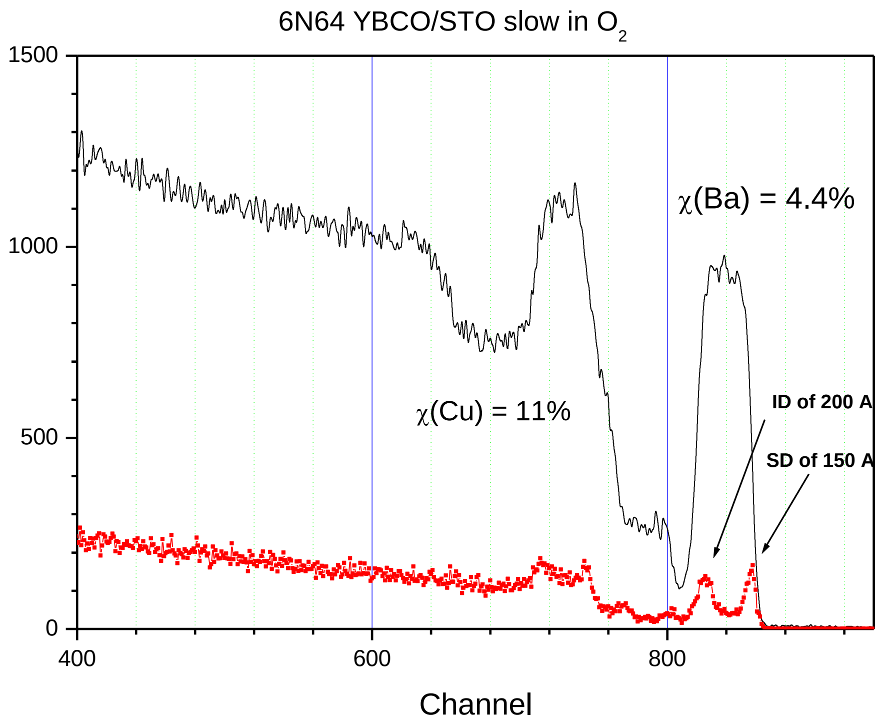
2θ	“c”
15.14	11.69
15.24	11.62
15.26	11.60

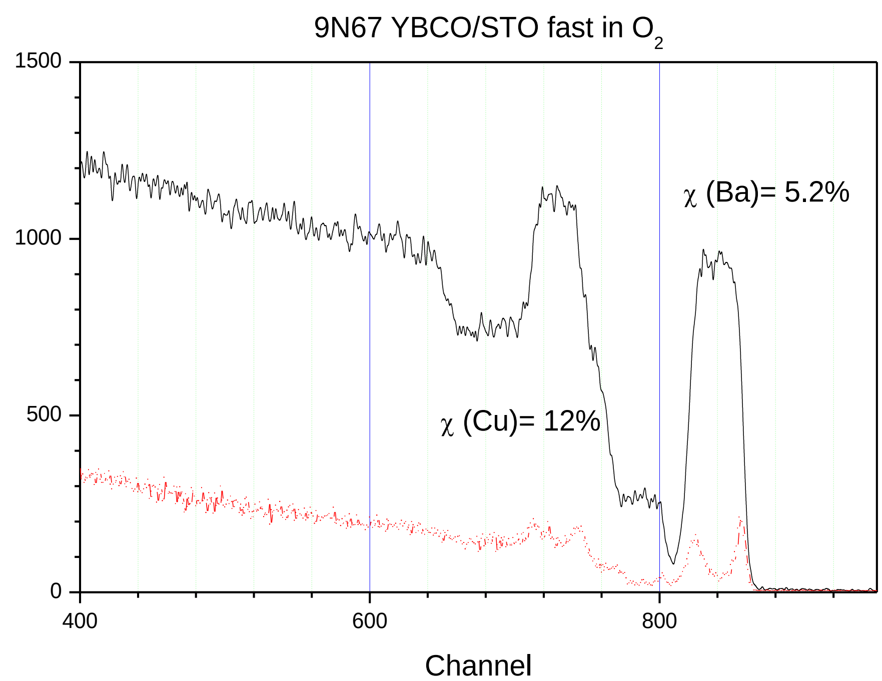




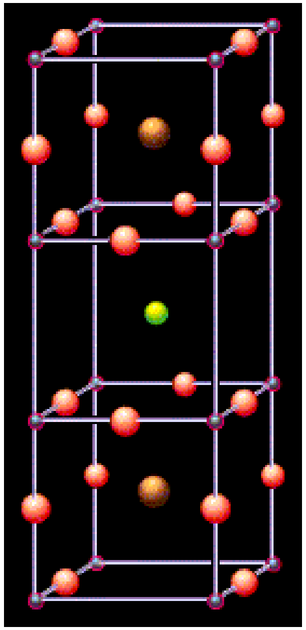


- The YBCO films have their (a,b) planes parallel to the STO (100), as a result of the presence of well pronounced (00l) peaks.
- Highly texture growth evidenced by (005) YBCO rocking curve. FWHM in the range of 0.2° to 0.3°.
- The difference in the “c” lattice parameter revel difference in the oxygen content.





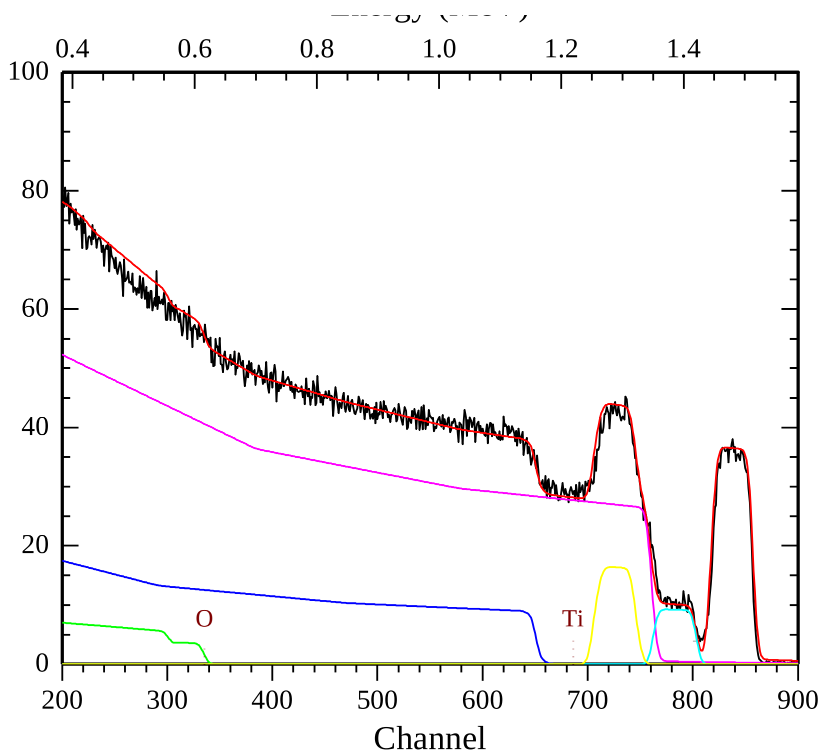
↑ χ - (weaker channeling) - c ↑ O ↓



- The precise χ_{min} values measured on YBCO films with the same "*c*"-axis angular spread (~0.1- 0.8°) <u>depend upon the oxygen content</u>. In fact, higher χ_{min} values are observed on the films having a higher value of *"c"* parameter – characteristic of low oxygen content !

- High crystalline quality – near 0° epitaxial growths.

“Sample A” - RBS – high precision simulation



La1:

Thick 600 A

Comp: Y 1.1 BA 1.85 CU 3 O 7 AR 0.02

La2:

Thick 500 A

Comp: Y 1.1 BA 1.85 CU 3 O 7 AR 0.12

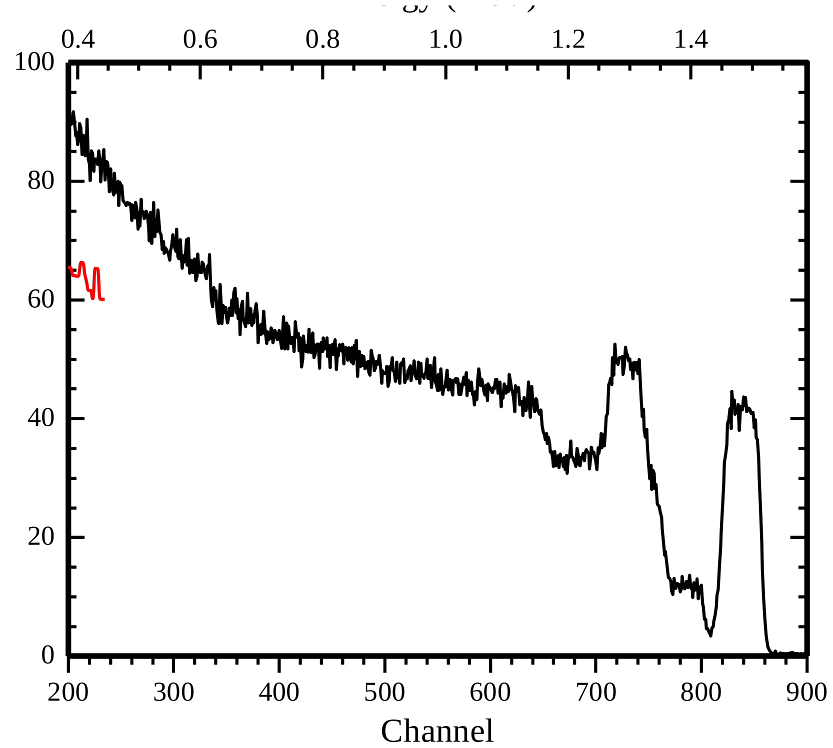
La3:

Thick 100000 A

Comp: O 3 SR 1 TI 1

6N64ra YBCO/STO slow in oxygen - superconductor

"Sample C" – RBS - high-precision simulation



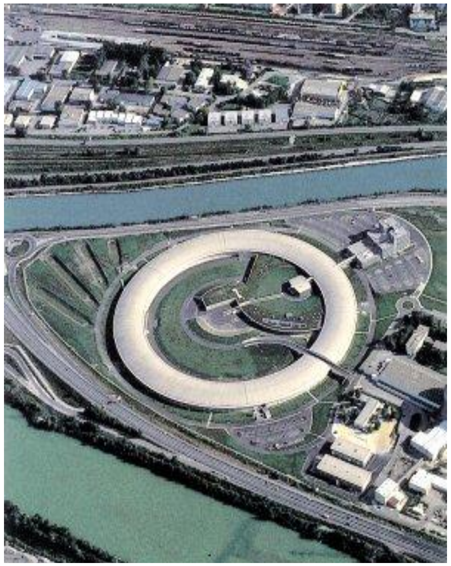
Relative film stoichiometry for YBCO/STO quenched in vacuum in different depths as deduced from RBS

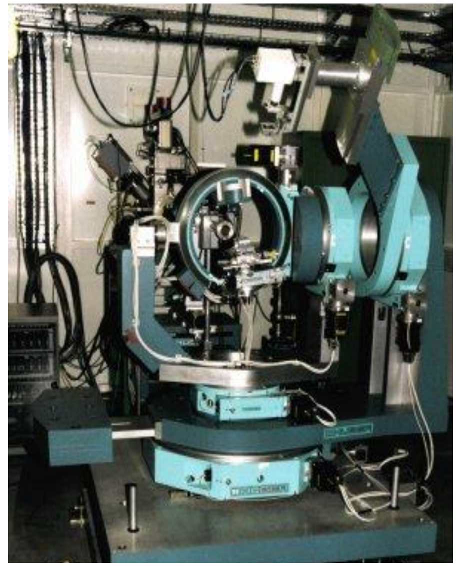
Depth [nm]	**Y**	**Ba**	**Cu**	**O**	**C**	**Sr**	**Ti**
100	1.1	1.8	3	6	0.4	-	-
26	1	1.8	2.8	6	-	-	-
14	-	0.6	1.8	2	1.6	1	0.2
8	-	0.8	1	3	1	-	-
10000	-	-	-	3	-	1	1

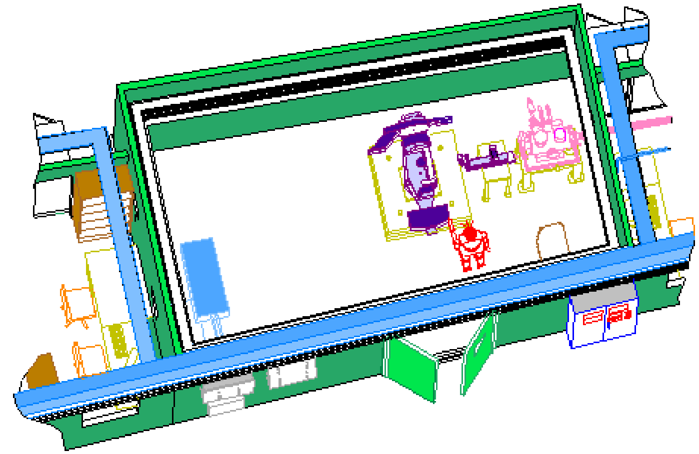
About 20 nm thick interface layer of $BaCuO_2$ is formed when the oxygen supply is not sufficient for the SC phase formation.

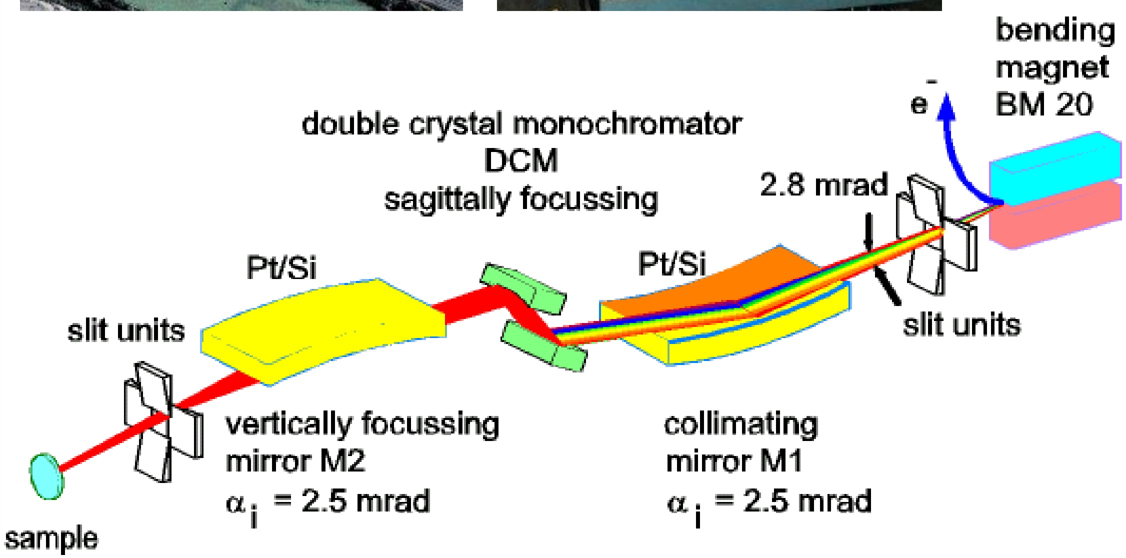
Synchrotron radiation experiment

ROBL at ESRF - Grenoble

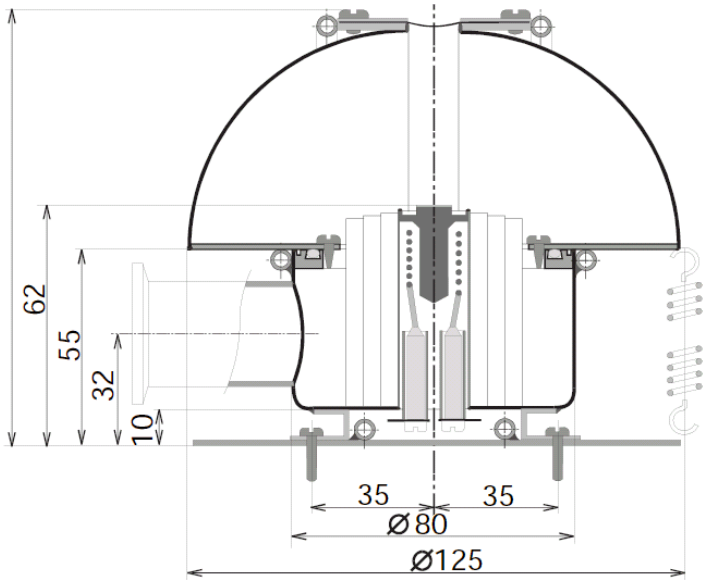




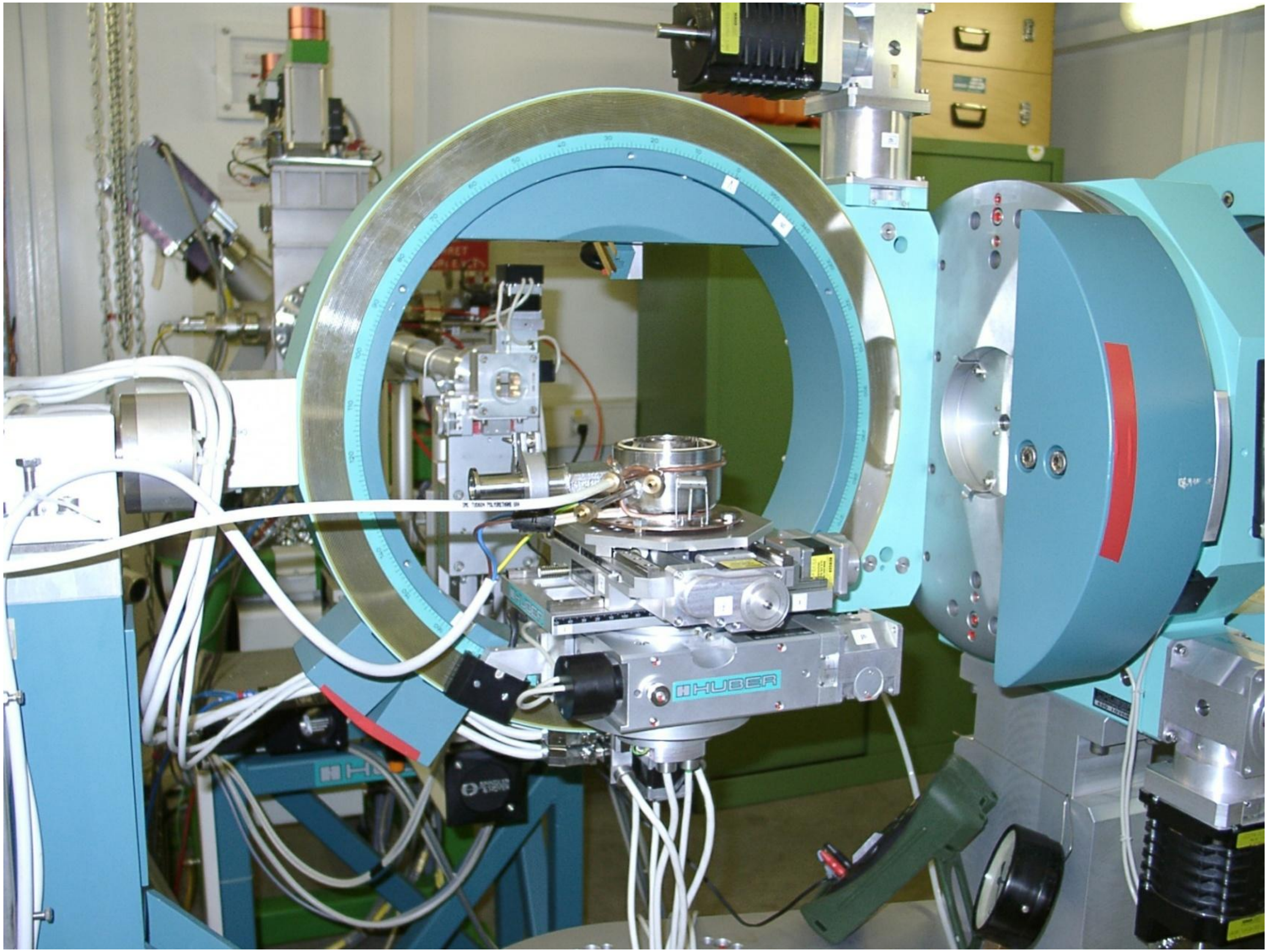


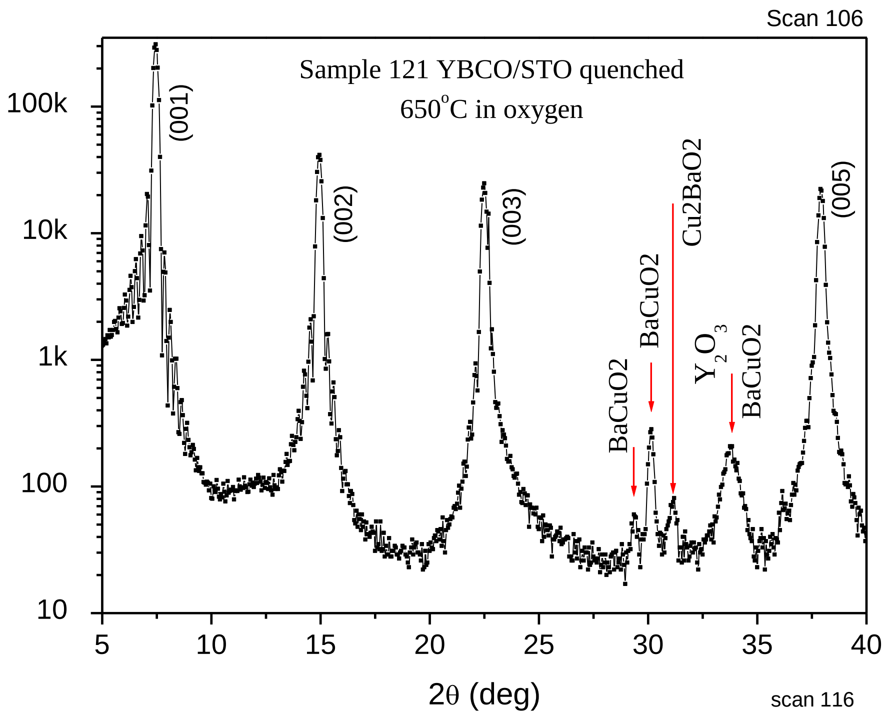


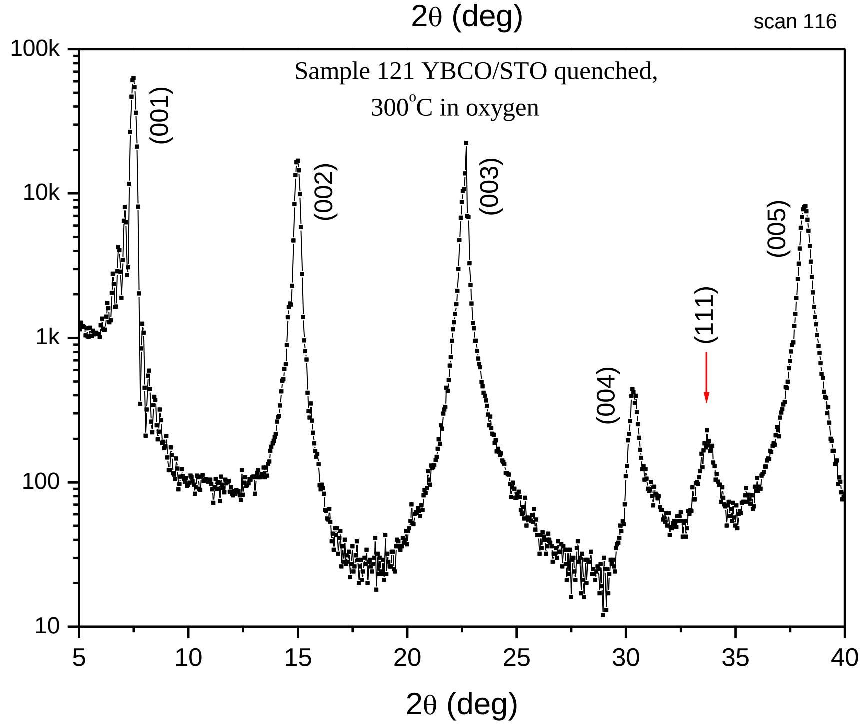
Measured structure --- 40 nm quenched in vacuum YBCO deposited on $SrTiO_3$ (STO) [100] substrate.



The Goniometer





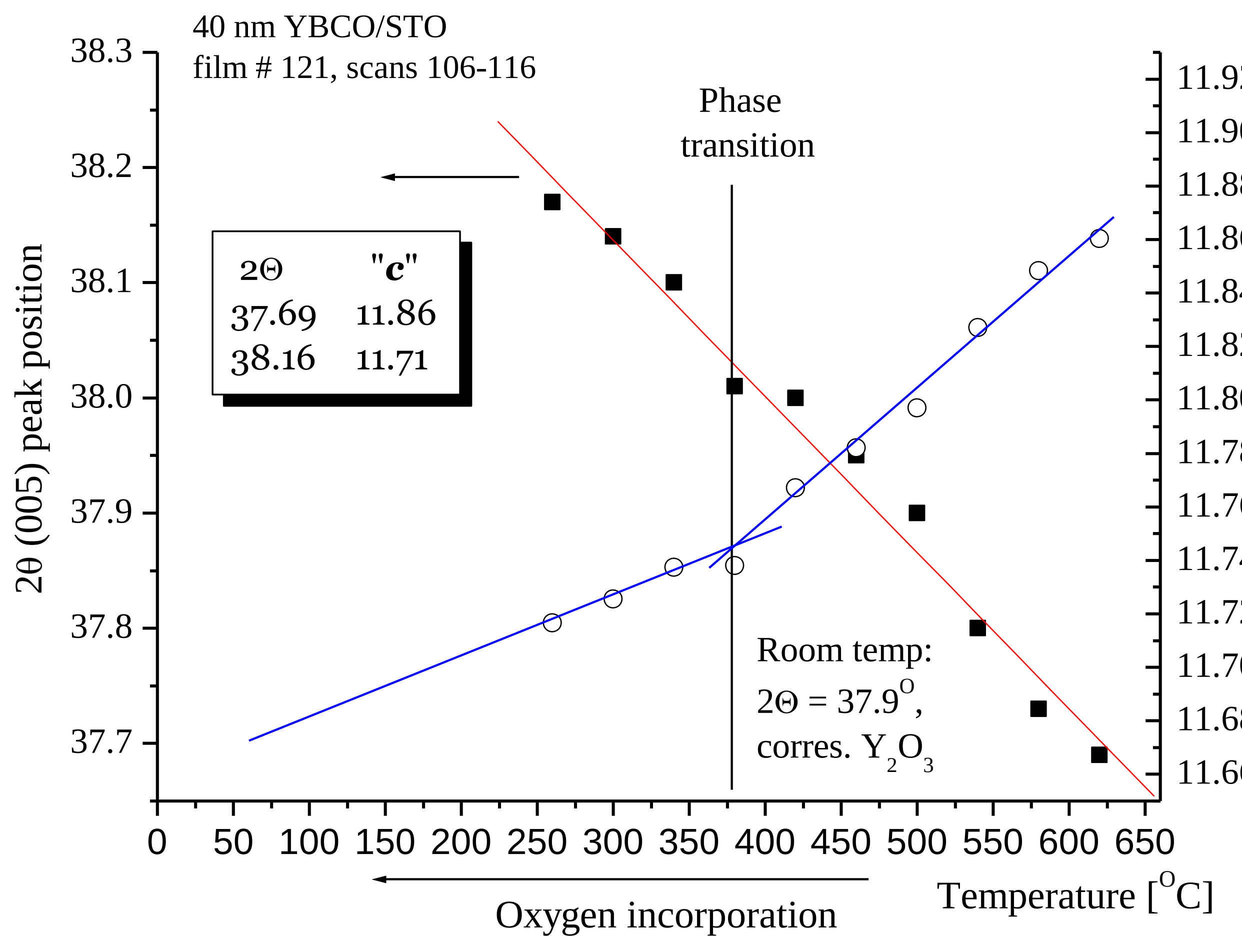


Other phases:

Y_2O_3 - bcc;

$BaCuO_2$ – cubic

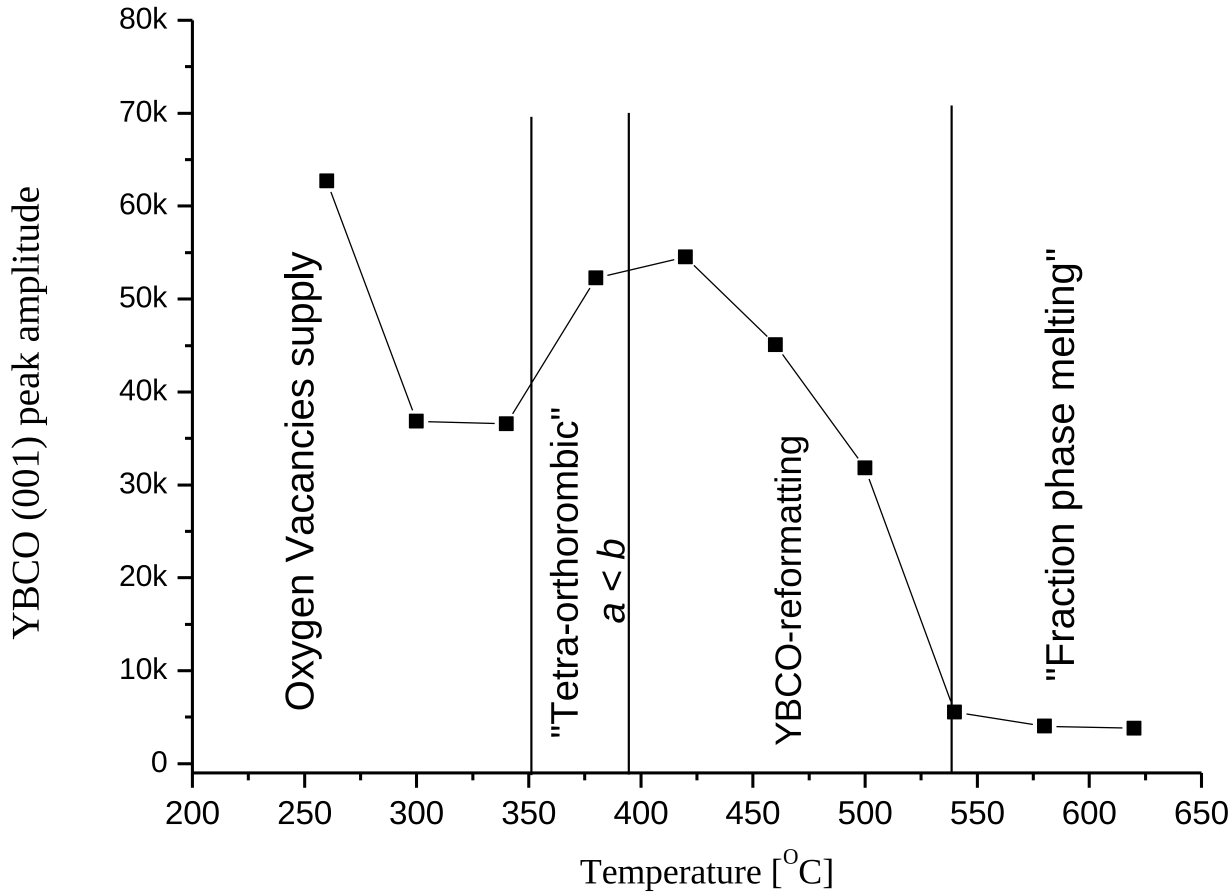
Cu_2BaO_2 - tetragonal



Tetragonal phase

Orthorhombic phase

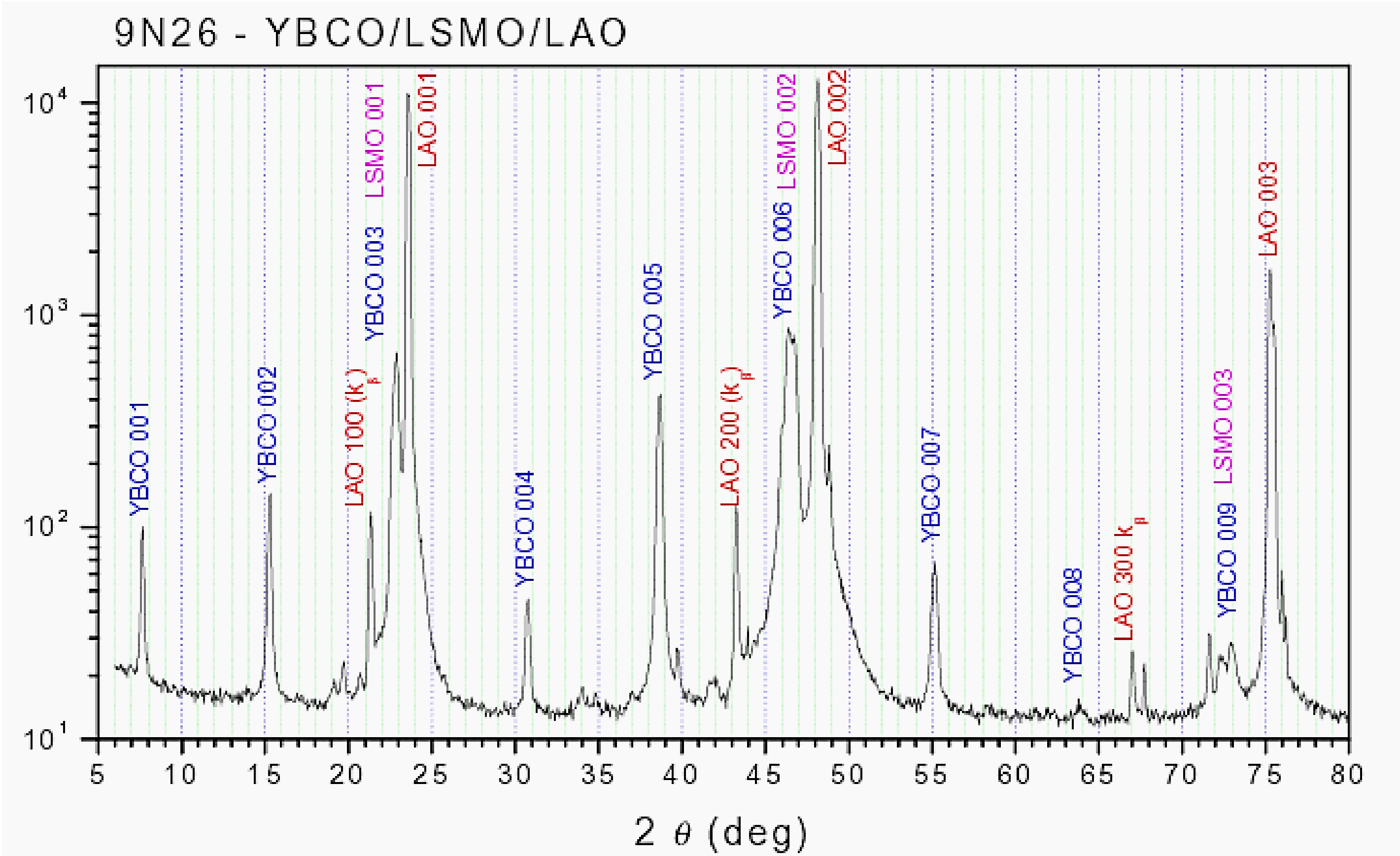
Phase dynamics



If X-ray scans are acquired at very grazing angle at specular mode a regular undulating spectrum appears known as **Laue fringes**. The repetition frequency is directly related with the film thickness and it is typical for high crystalline film quality. Such Laue fringes are observed in the studied sample # 121 YBCO/STO and they begin to clearly appear after scan # 113, or bellow 380^{o}C.

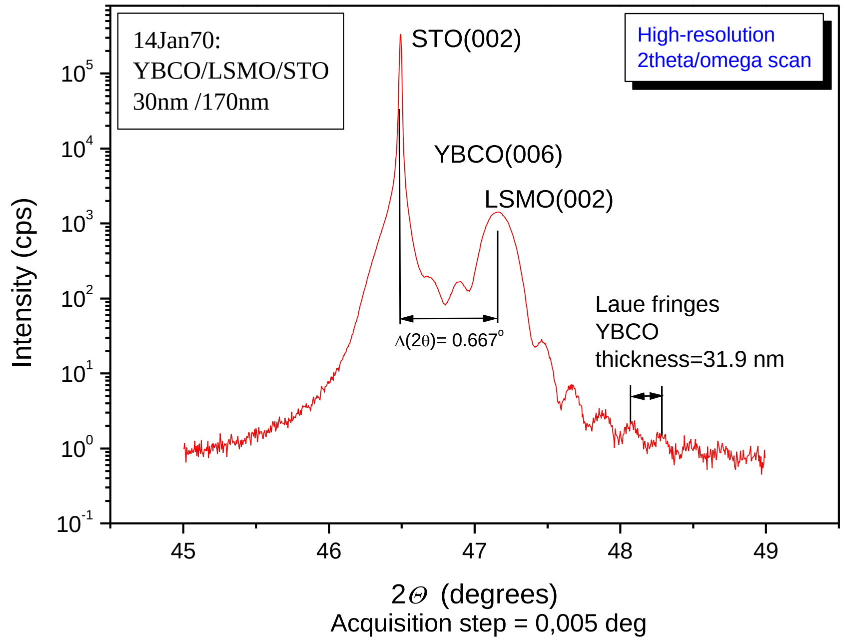
Measured structure - YBCO/LSMO/LAO

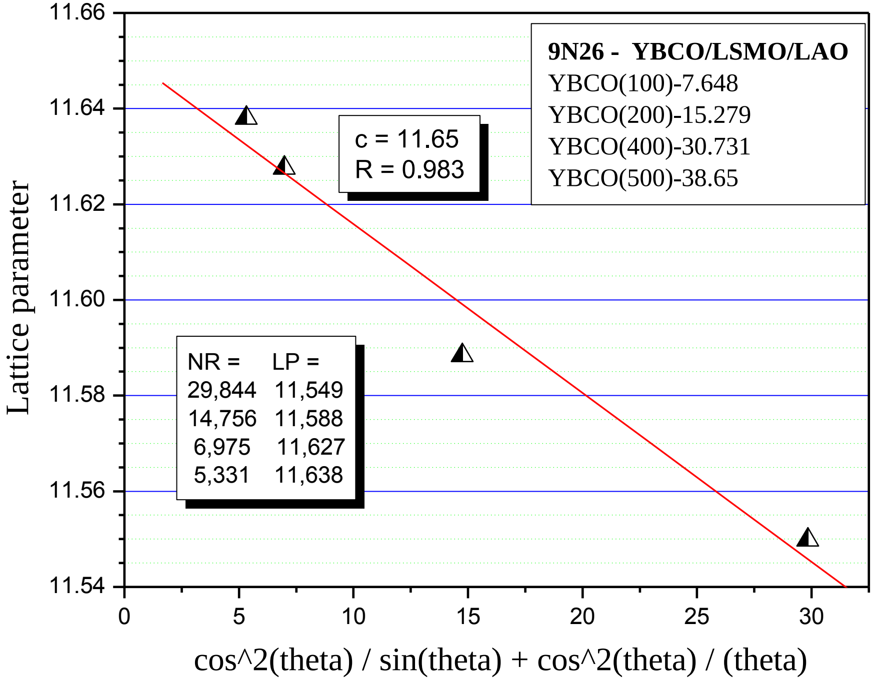
The LAO (002) at R.T. peak is visible at $2\theta = 47, 86^o$. If LAO lattice is a = 3.778 Å, the synchrotron radiation is $\lambda_{Ro} = 3.778 * \sin(47.86/2) = 1.5324$ Å

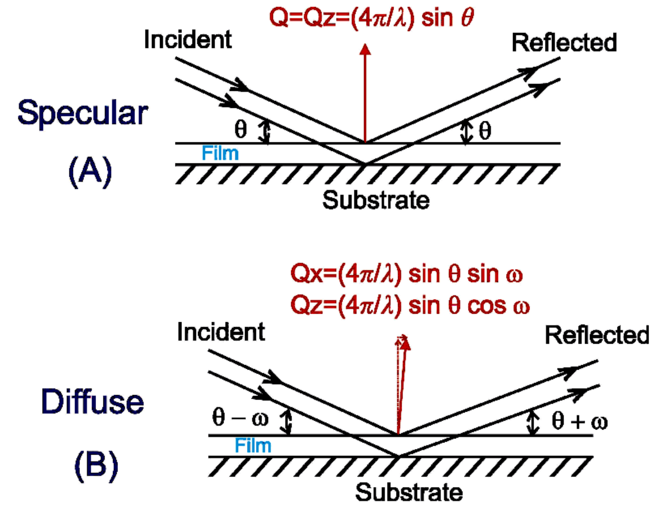


YBCO- slowly cooled in oxygen - superconducting

The reverse deposition order (LSMO on top of YBCO) renders YBCO non-superconducting. During LSMO sputtering the oxygen partial pressure is not high enough and the YBCO film deoxygenates.







X-ray Reflectivity

Specular reflectivity data are analyzed to determine the depth dependence of the electron density of the material of interest.

In diffuse or off-specular reflectivity measurements of the intensity as a function of Q_x allow a determination of the of surface or interface roughness.

Conclusions

The process of the phase transitions in HTSC YBCO thin film were studied "*ex-situ*" by means of Real Time Synchrotron Radiation.

A special set-up was constructed for this purpose to fit the goniometer of the SR-XRD experiment and to operate at high temperature in oxygen atmosphere.

The analyzed dates show by two independent ways the exact ranges of phase existing and phase transitions.

High-precision RBS spectra taken in channeling and random geometry confirm also the existence of these phases.