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LABORATORY OF CONDENSED MATTER PHYSICS AND NANOMATERIALS FOR RENEWABLE ENERGY

REMARKABLE INFLUENCE OF HEAT TREATMENT IN STRUCTURAL, ELECTRICAL AND MAGNETIC PROPERTIES IN HIGH T_C SUPERCONDUCTOR $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$

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CEC/ICMC 2013 , Anchorage, Alaska, USA, June 17 - 21, 2013
1MOrC2 orals , Convener: Eric Hellstrom (NHMFL), Location: Kahtnu 2, 10h 30

INTRODUCTION

Aim of the work : **Structural, Electrical and Magnetic properties**

Considered magnitudes : **Tc, irreversibility line, resistivity, critical current density Jc.**

Aspect of the work : **Experimental.**

Studied material : **$(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$.**

Material interest : **Double interest:**

Technological

Academic

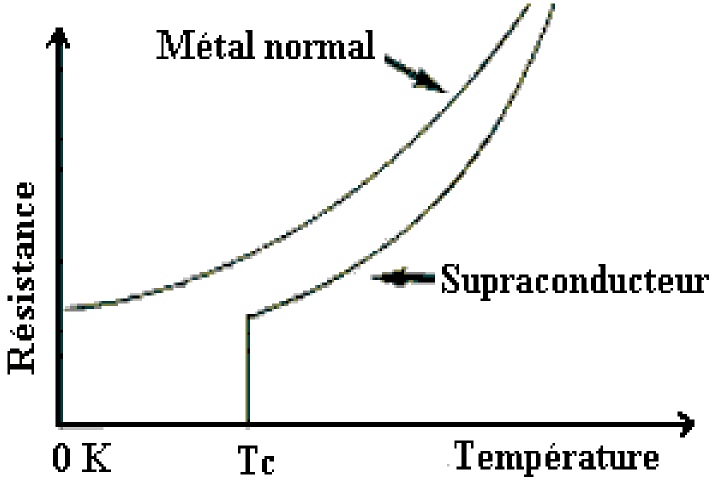
Technological

Academic

- Mecanisms of superconductivity;
- Observed Effect of heat treatement on physical properties Of high Tc Superconductors;

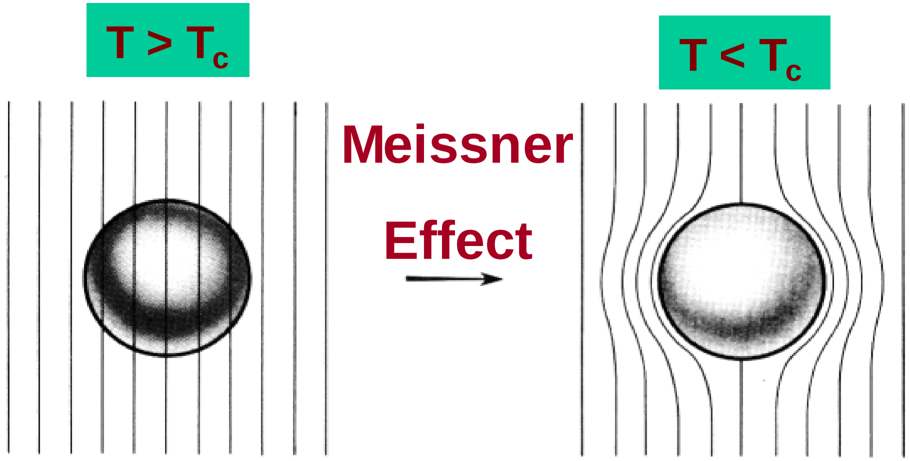
INTRODUCTION

Définition of a superconductor ?



ρ = 0 for T < Tc

Thermal variation of the resistivity

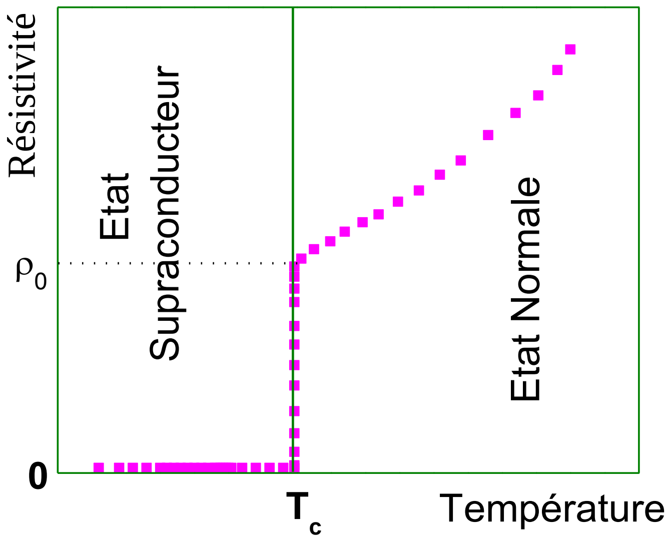


B=0 for T< Tc

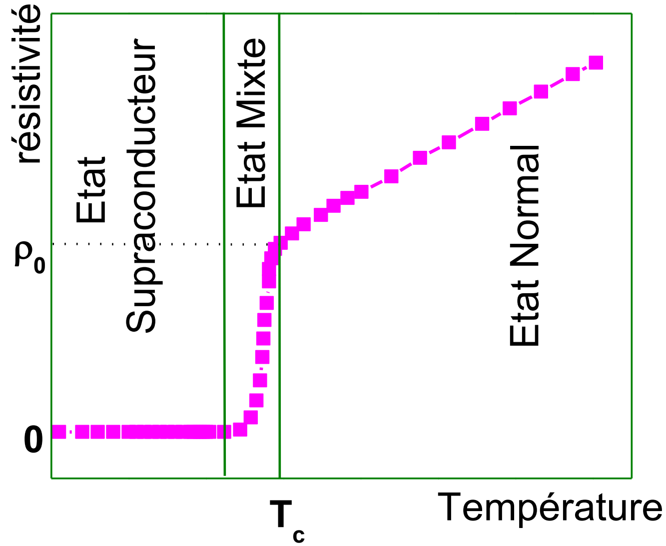
Exclusion of the magnetic field by a superconductor

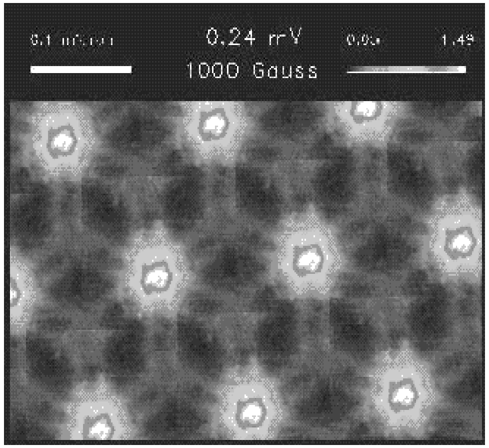
Two types of superconductors

Type I

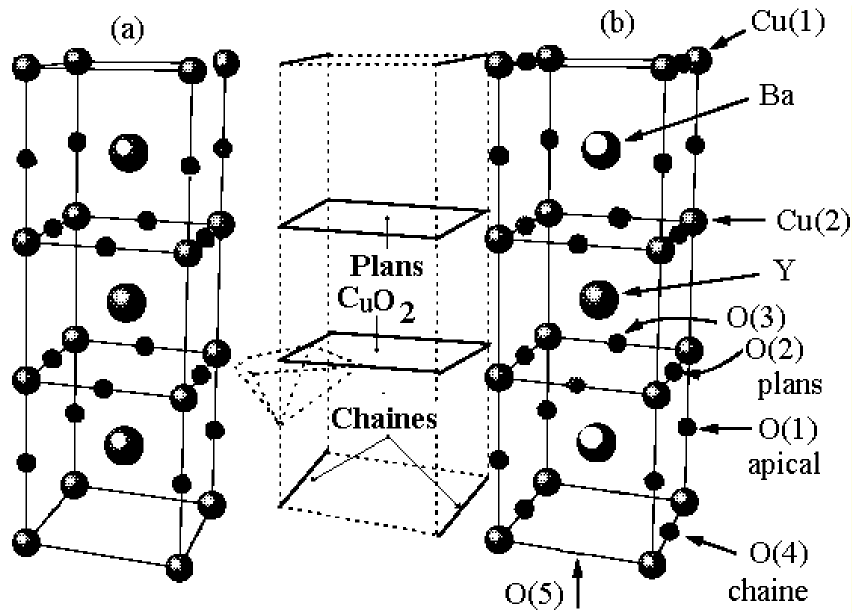


Type II





- **Until 1986 :** T_c=23K Nb_3Ge
- **Déc 1986 Bednorz et Müller** T_c=35K $La_{2-x}Ba_xCuO_{4-9}$
- **1987 : Wu et al** T_c=92K $YBa_2Cu_3O_{6+z}$
- **To day** T_c=135K HgCaBaCuO
- **Actual record under pressure** T_c=164K HgCaBaCuO



$YBa_2Cu_3O_{6+z}$.

Crystalline Structure of :

(a) $YBa_2Cu_3O_6$ (z=0)

(b) $YBa_2Cu_3O_7$ (z=1)

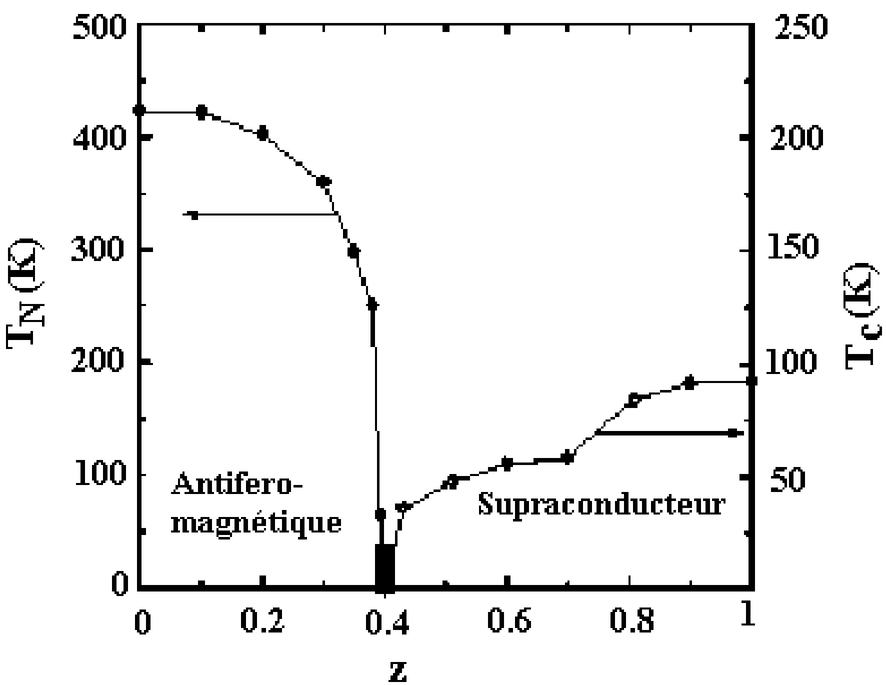


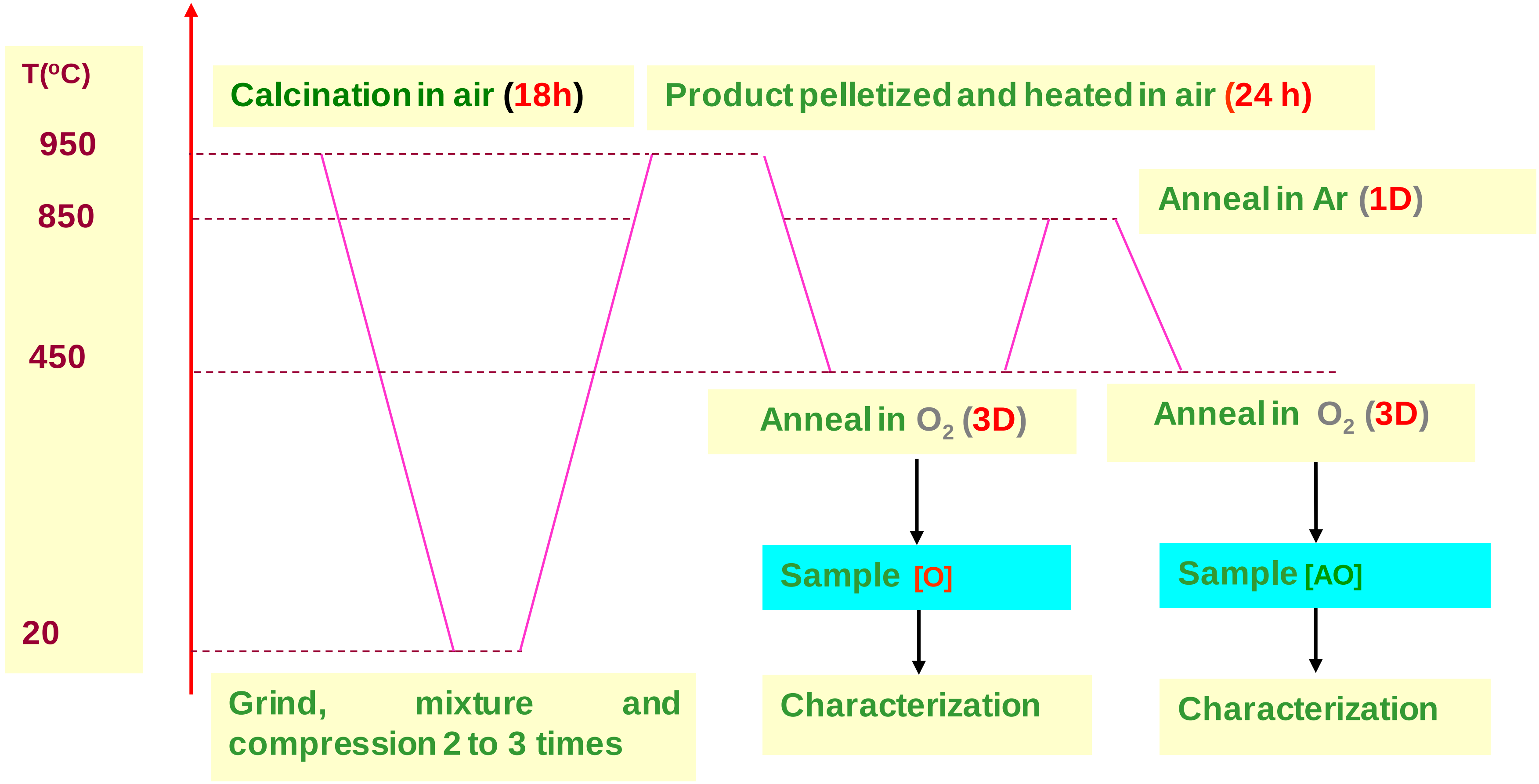
Diagram Phase of $YBa_2Cu_3O_{6+z}$ as a fonction of the rate of partial oxygen z

EXPERIMENTAL

- Preparation of the samples
- X-ray diffraction (XRD) with Rietveld refinement
- AC magnetic susceptibility
- Resistivity
- Effect of heat treatments

Preparation of the samples

by solid-state sintering of the respective oxides and carbonates



- **Iodometry** z in $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$

- **XRD** with **Rietveld refinement** a, b, c, z, α,

Atomics positions, interatomics distances

- **alternatif Susceptibility**

$f=1500$ Hz ; $H_{ac}=0.11$ Oe ; $0 < H_{dc} < 200$ Oe

χ' T_c, ΔT_c, S

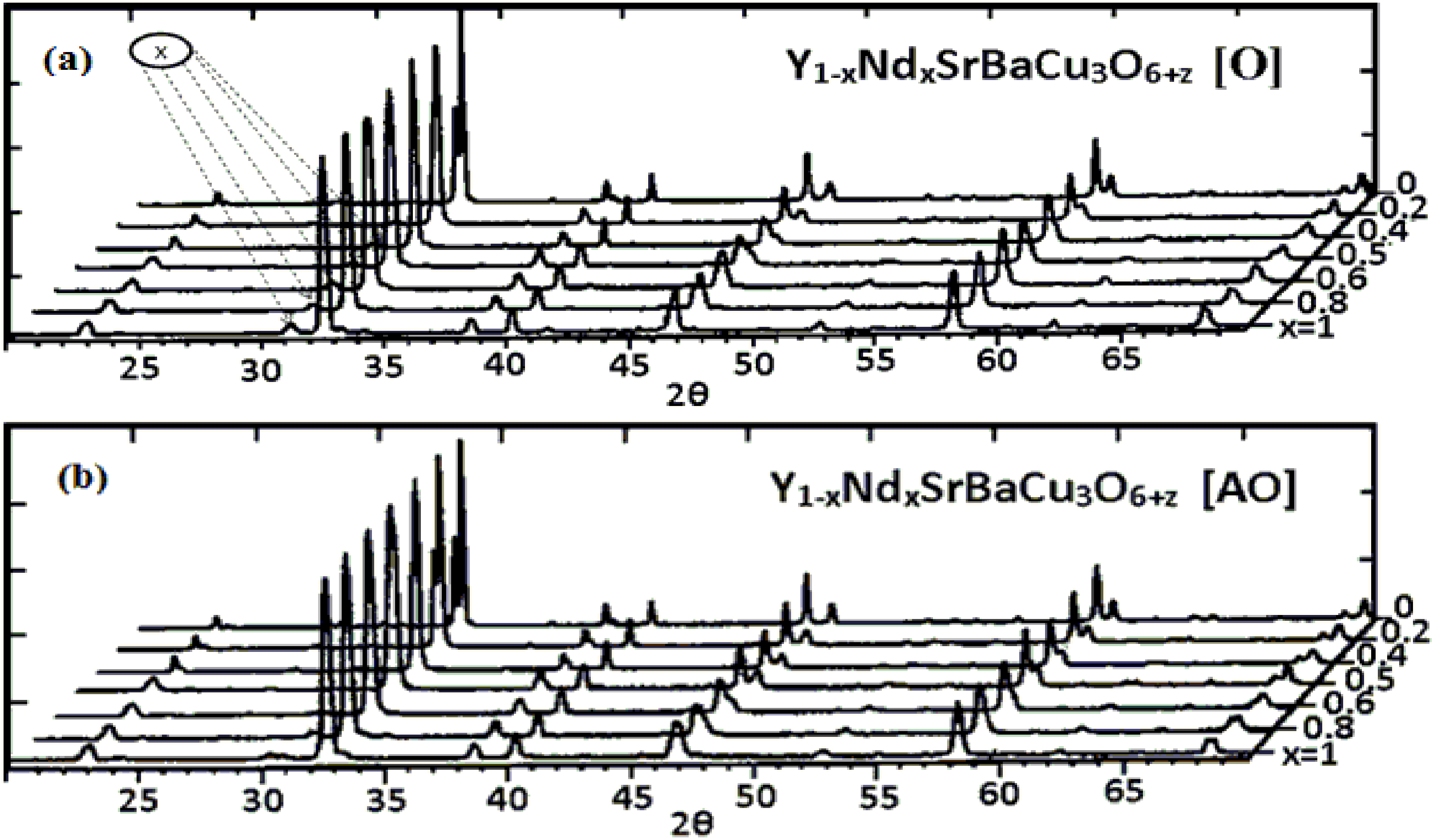
$$\chi_{ac} = \chi' + i\chi''$$

χ'' $T_p(H)$, I.L, ΔT_p

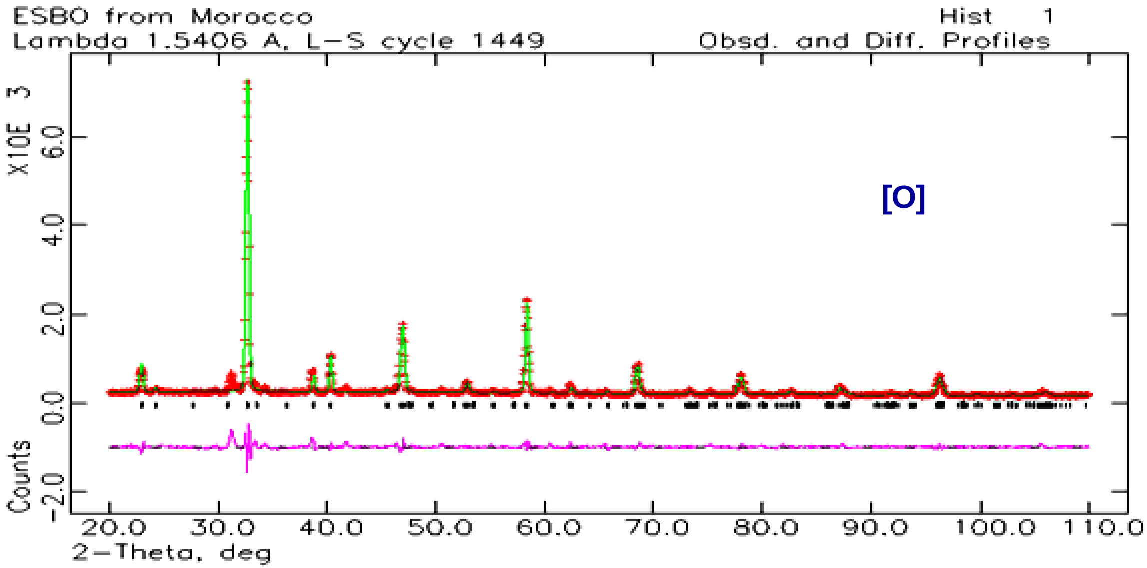
- **Résistivité $\rho(T)$** : T_c, ΔT_c $\rho=\rho_0+\alpha T$ pour $T>T_c$

Experimental Resuls

Cristalline Structure



X-ray (Cu Kα) diffraction patterns of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$ as a function of x and heat treatment. Samples [O] annealed in oxygen at 450°C and samples [AO] heated in argon at 850°C followed by annealing in oxygen at 450°C. (x=impurity peaks.)



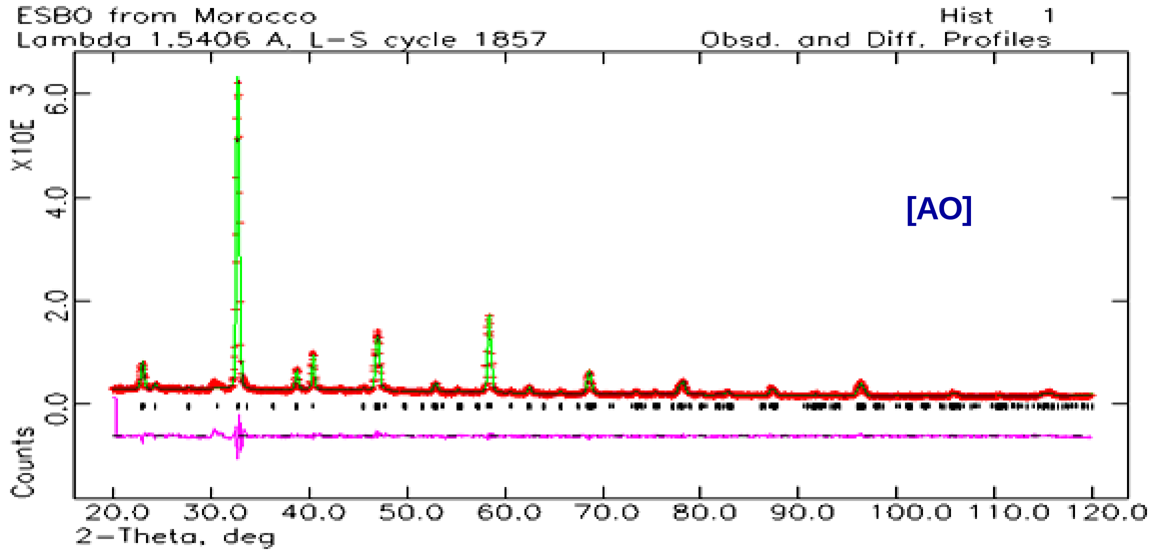
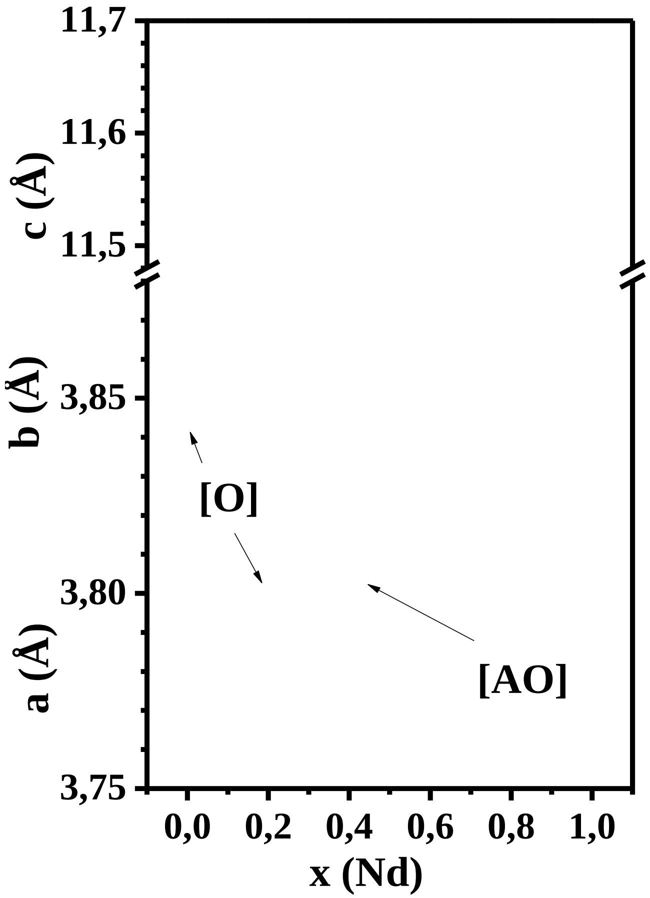
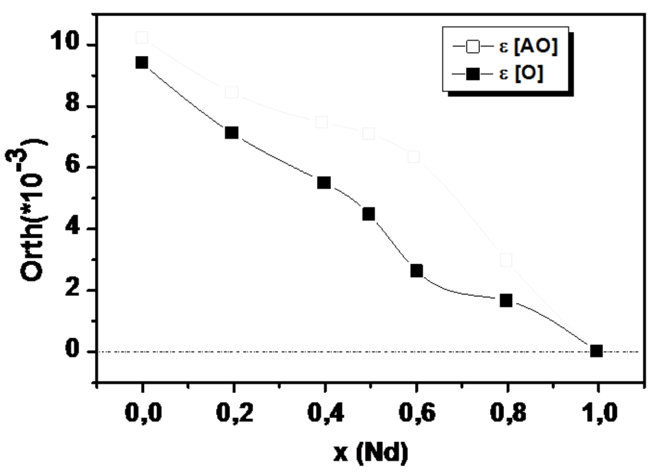


Fig.2 XRD pattern of $NdSrBaCu_3O_{6+z}$ (x=1): Observed (+), calculated with Rietveld refinement and difference profiles. Sample [O] annealed in oxygen at 450°C and sample [AO] heated in argon at 850°C followed by annealing in oxygen at 450°C. Reflection positions are marked with vertical bars.

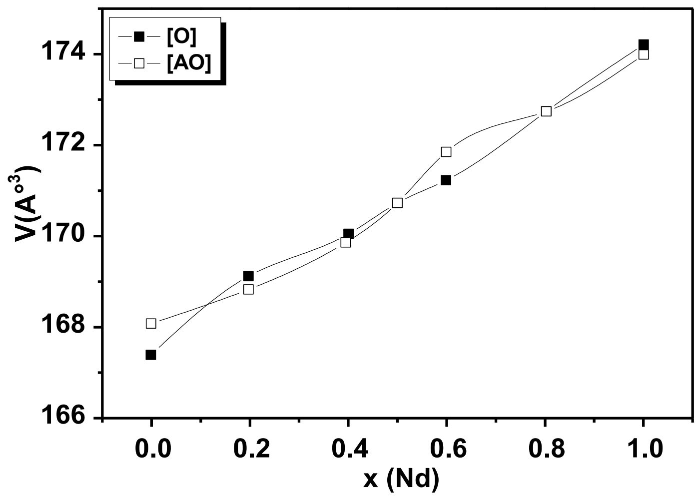
Crystalline parameters and the orthorhombicity of $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$ as a function of x and heat treatment



Variation of the parameters a, b and c

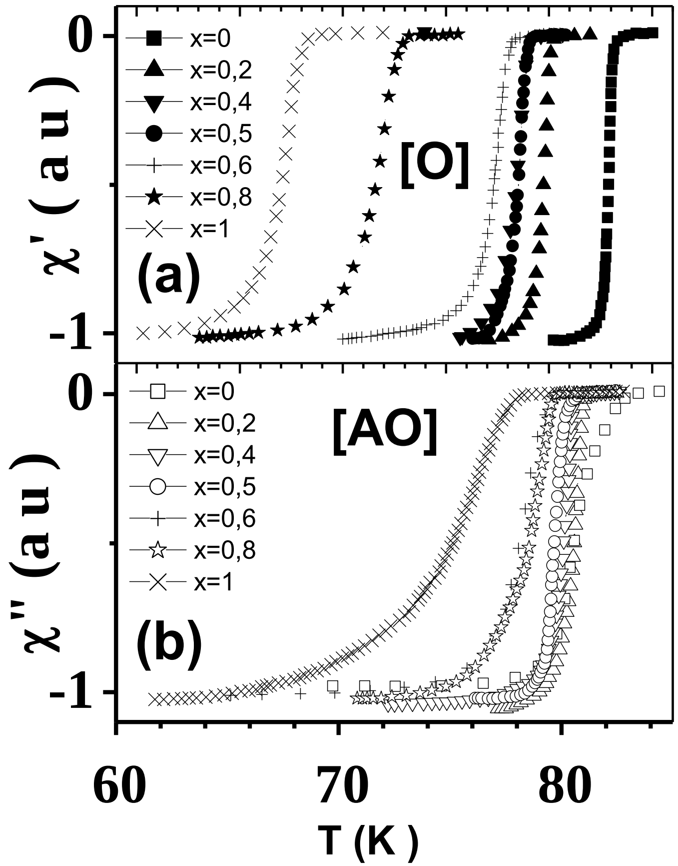


Variation of the orthorhombicity



Variation of the volume V of the unit cell

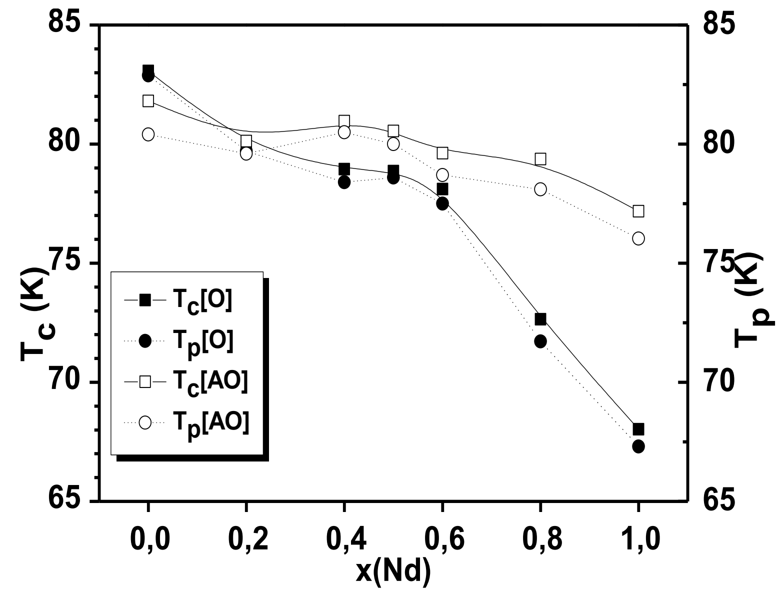
Real part of the AC magnetic susceptibility and the crirical temperature Tc



(a,b) χ'(T) of (Y1-xNdx)SrBaCu3O6+z as a function of x and heat treatment.

* For each x(Nd),
Tc increases for x≥ 0.2

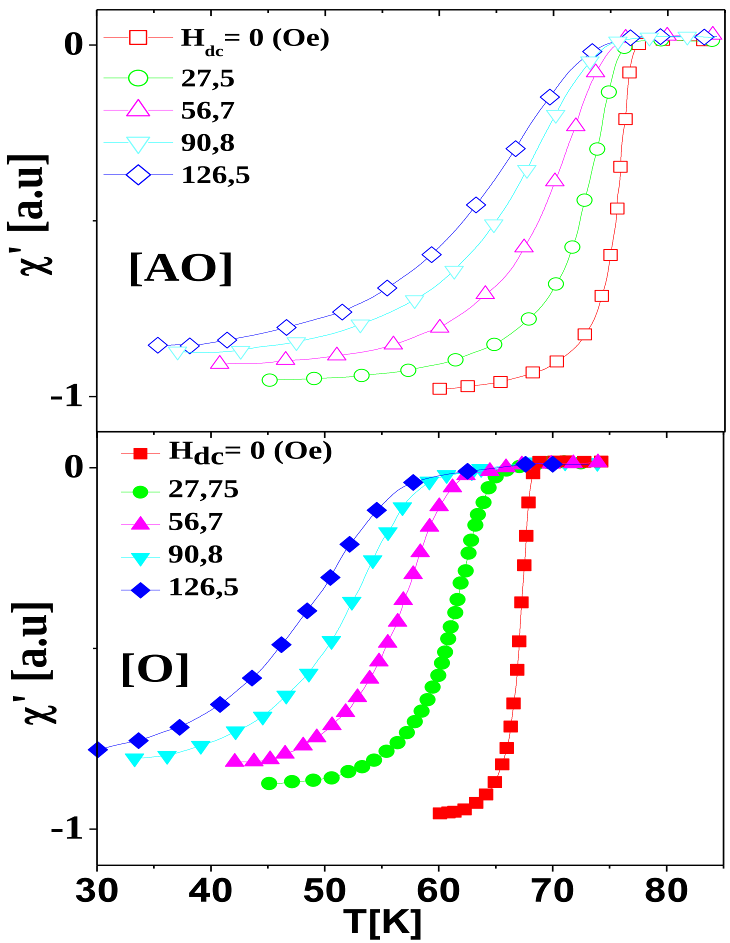
* When x increases:
- Tc = decreases
- Tp (χ'') follows Tc (χ')



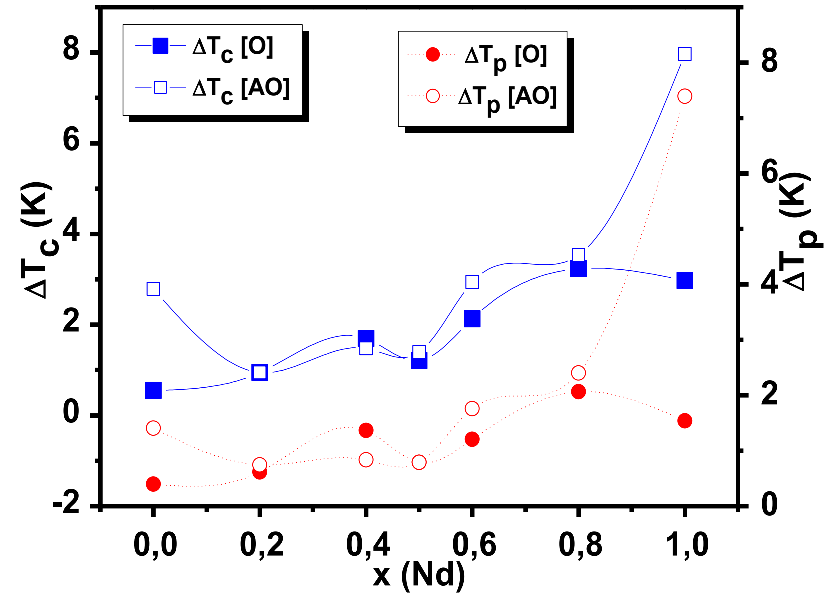
T_c and T_p of $(Y1\text{-}xNd_x)SrBaCu_3O6+z$ as a function of x(Nd) following the [O] and [AO] heat treatments.

Real part of the AC magnetic susceptibility and shielding effect

$(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$



$\chi'(T)$ of $NdSrBaCu_3O_{6+z}$ as a function of T and heat treatment at five fields H_{dc}



ΔT_c and ΔT_p of $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$ [O] and [AO]

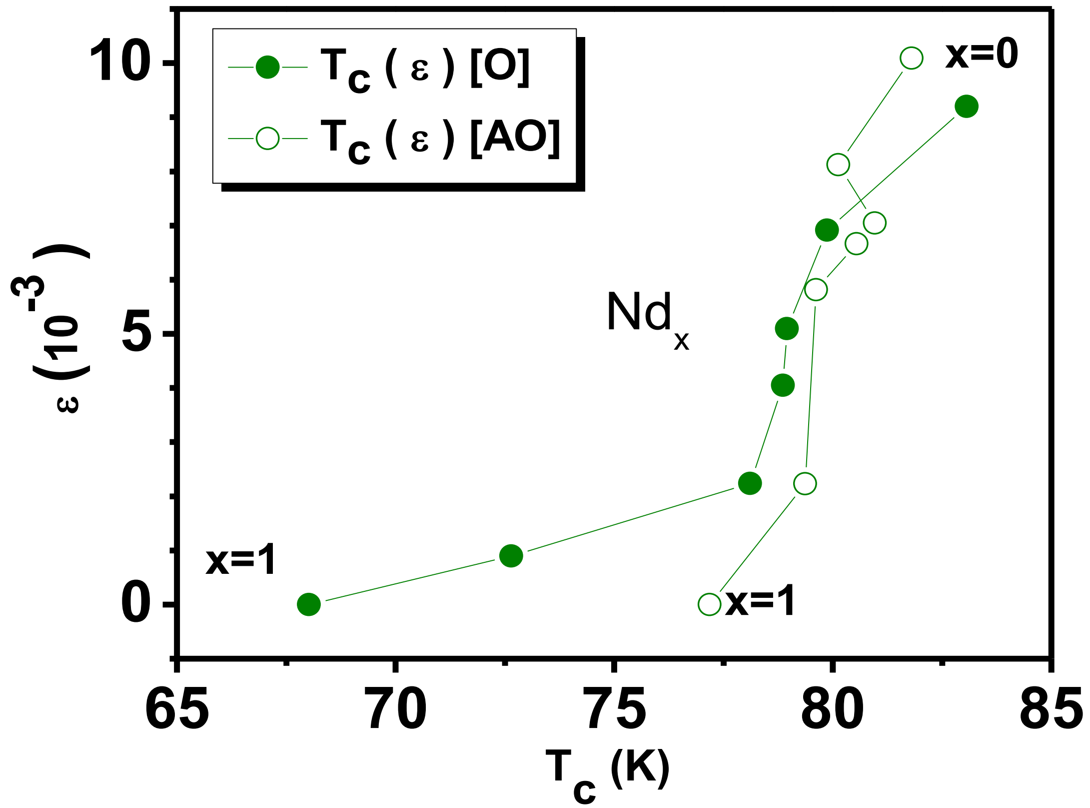
For each x(Nd), (Exemple x=1)

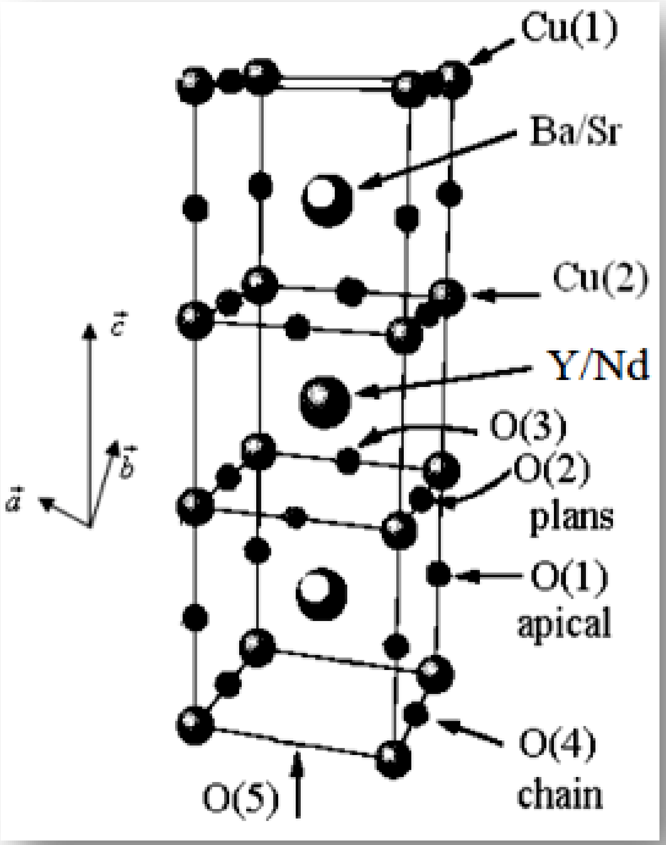
*** When H_{dc} increases:**

- **Tc = cst (Tc intrinsic)**
- **ΔTc increases**

*** For each H_{dc} :**

The [AO] treatment increases ΔTc





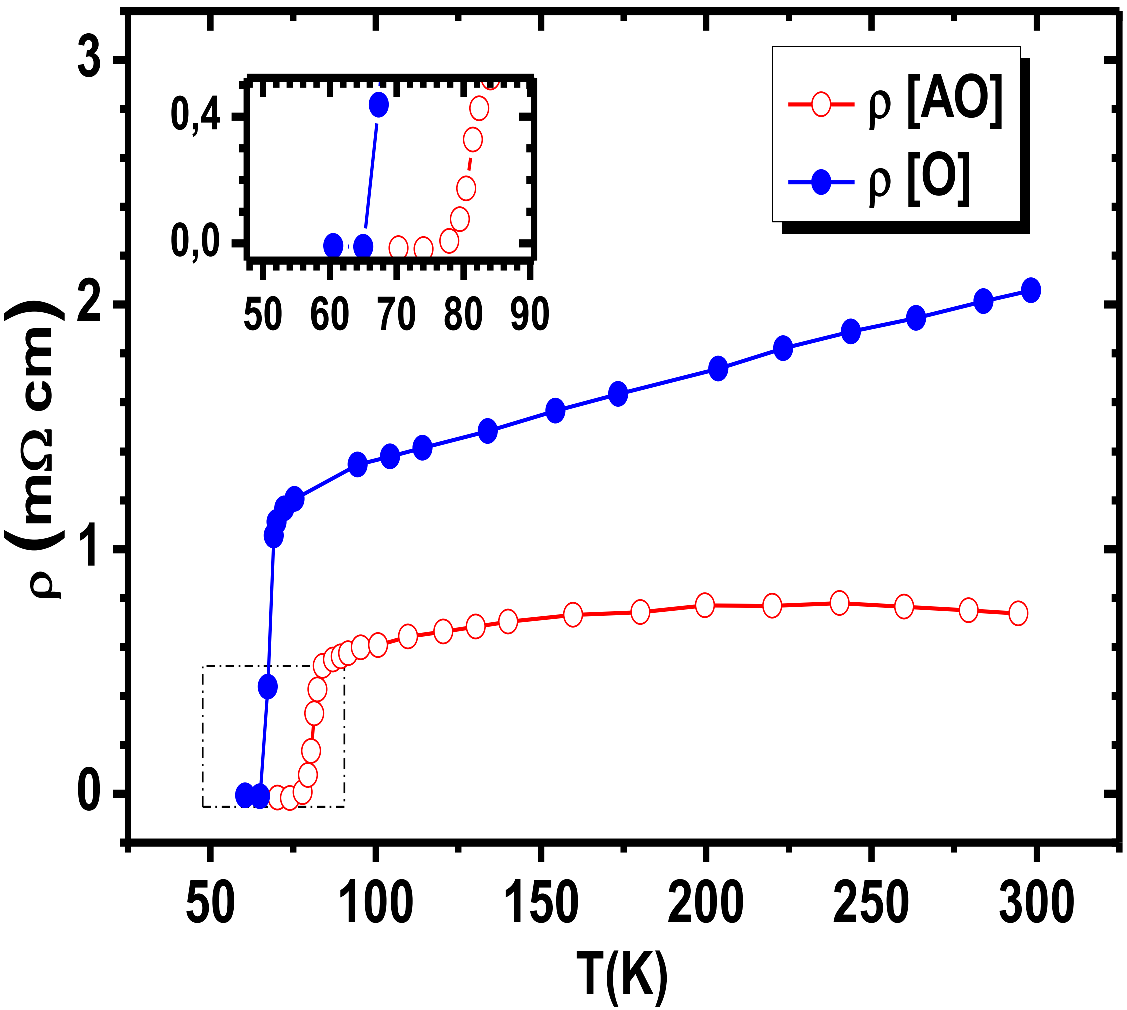
For each x the [AO] heat treatment increases

*** The orthorhombicity $\varepsilon = (b-a)/(b+a)$ for $0 \leq x < 1$**

*** Tc (for x>0.2 and by 9.8 K for x=1)**

Variation of T_c as a function of the orthorhombicity ε and heat treatments in the left. The unit cell of $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$ in the right.

Resistivity



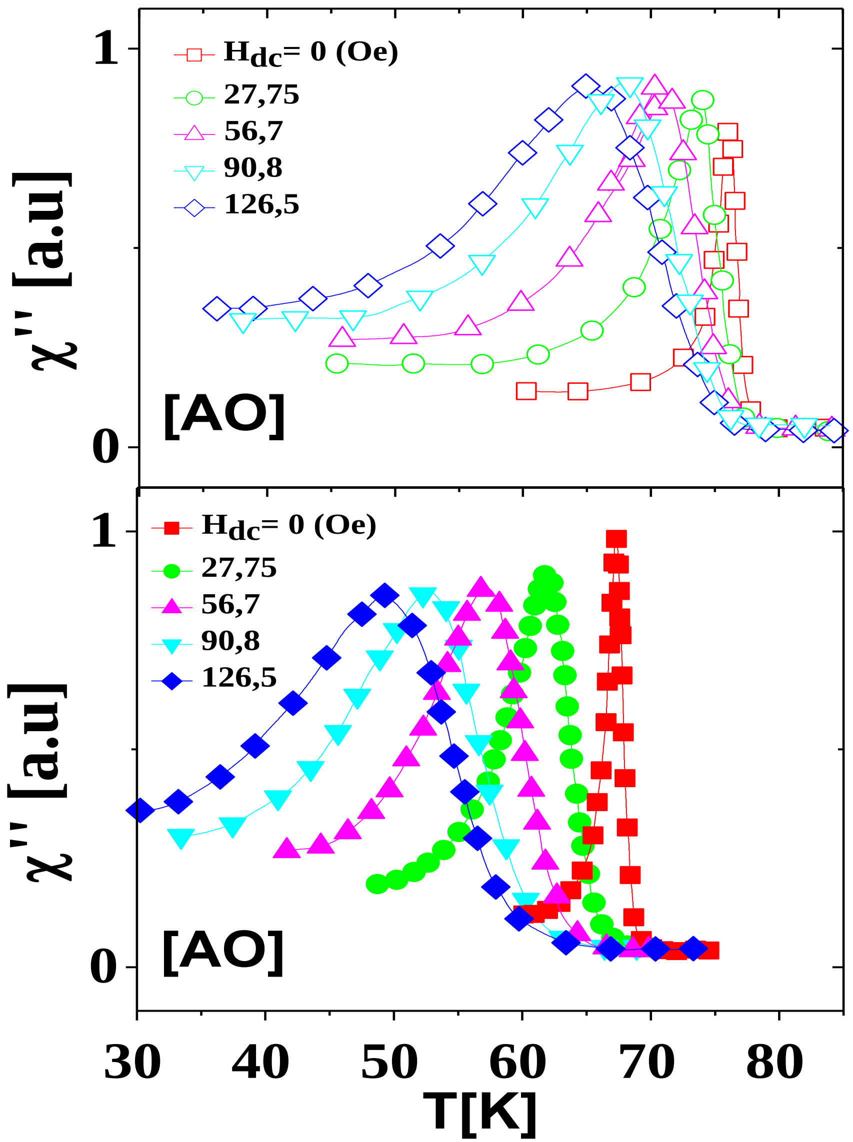
- The resistivity of $NdSrBaCu_3O_{6+z}$ *ρ [AO] < ρ [O].*

- *T_c (ρ =0) =T_c (χ')*
- *T_c (χ'')≈T_c(ρ=0).*

- In the normal state,
  $\rho = \rho 0 + \alpha T$. The treatment [AO] reduced considerably ρ0 and α This indicates a reduction of the interaction of carrier charges with phonons.

Variation of the resistivity ρ(T) of $NdBaSrCu_3O_{6+z}$as a function of the temperature and heat treatment.

Imaginary part of the AC magnetic susceptibility and irreversibility line



For each x(Nd), (Exemple x=1)

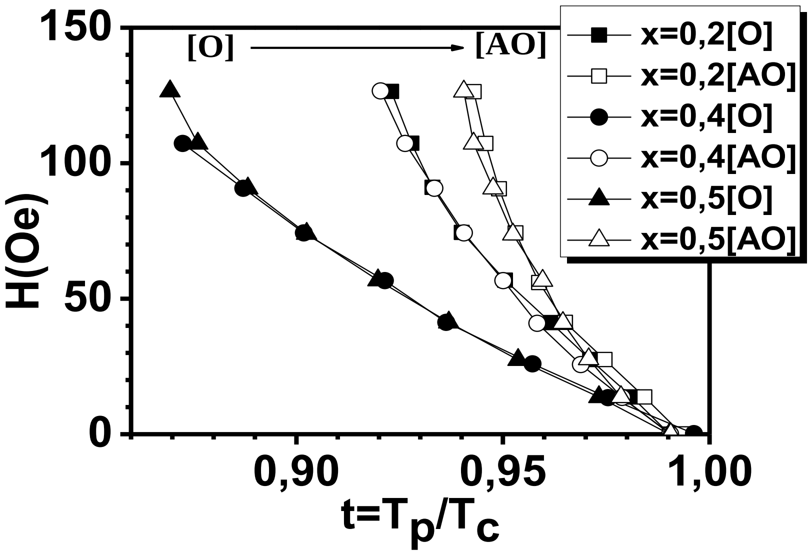
$NdSrBaCu_3O_{6+z}$

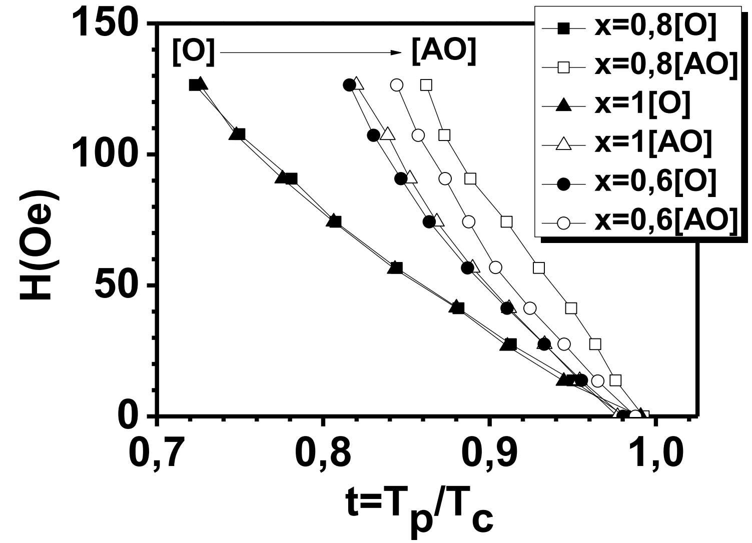
ΔT_p decreased: improvement of intergranular coupling.

When Hdc increase:

- **ΔT_p increase and decrease in the sample [AO]**
- **T_p decrease to low temperatures**

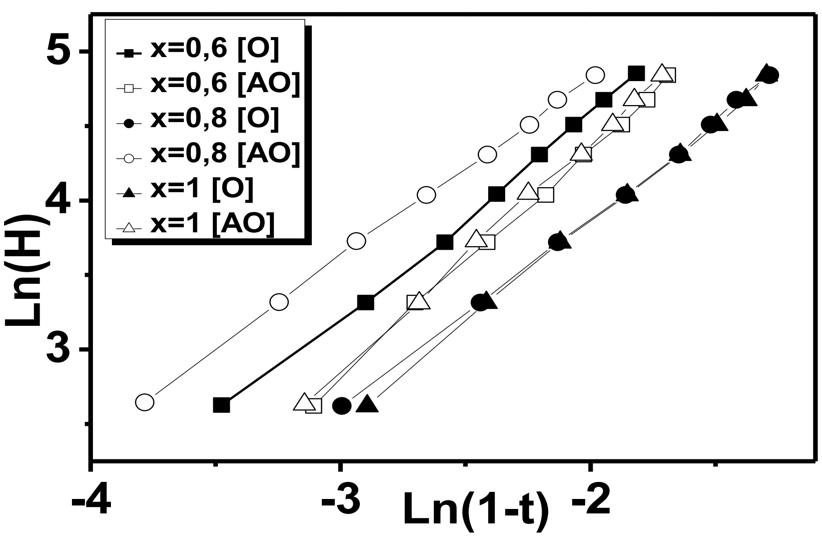
χ"(T) "Imaginary part" of $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$ as a function of the temperature and heat treatment at five fields Hdc (0 < Hdc < 126.5 Oe).

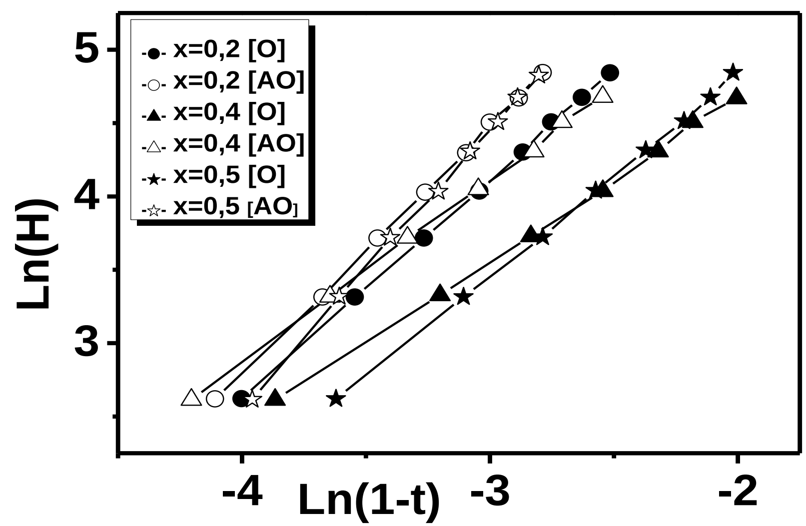




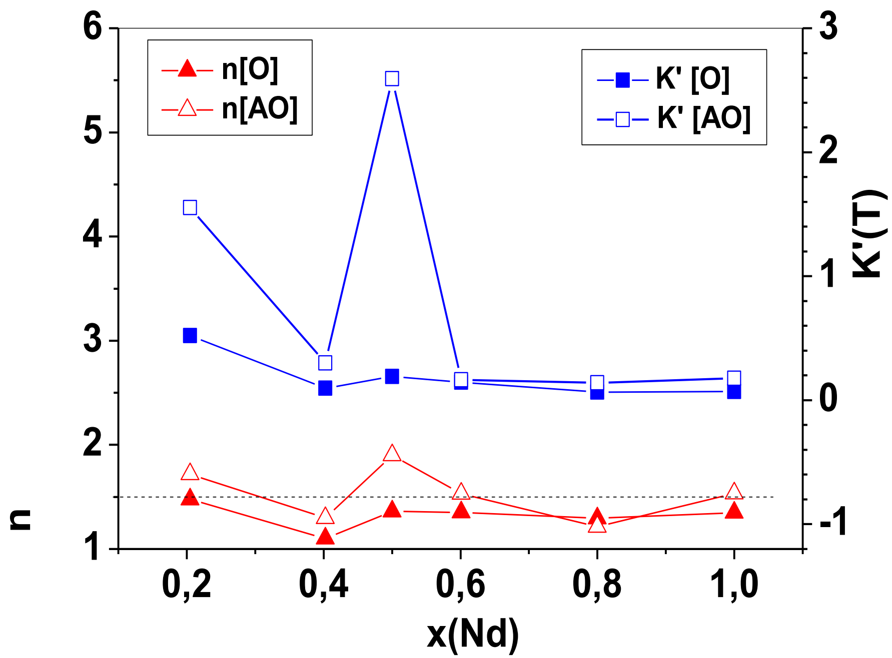
Ln (H) as a function of Ln (1–t) and heat treatment of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$

$$H = K'(1-t)^n$$





The field K' and the exponent n as a function of x and heat treatment of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$.



$$H = K' (1-t)^n$$

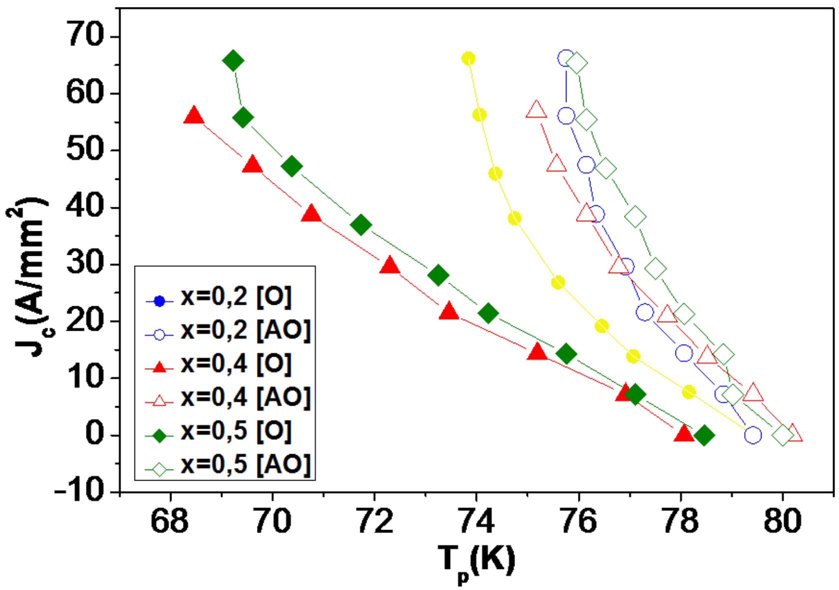
$$t = T_p/T_c$$

K' is the field necessary to reduce the intergranular critical current to zero in the limit of $T_p = 0$ K

TABLE 1: Superconducting structural am\nd magnetic Parameters

x	0		0.2		0.4		0.5		0.6		0.8		1	
h Treat	[O]	[AO]	[O]	[AO]	[O]	[AO]	[O]	[AO]	[O]	[AO]	[O]	[AO]	[O]	[AO]
Tc (K)	83,06	81,809	79,874	80,126	78,95	80,965	78,865	80,544	78,109	79,62	72,645	79,367	68,023	77,183
Tp (K)	81	77,8	79,7	79,6	78,4	80,5	78,6	80	76	74,5	71,7	78,5	67,3	75,5
ε (10^{-3})	9,19	10,09	6,91	8,12	5,09	7,04	4,04	6,66	2,23	5,81	0,89	2,23	0	0
K' (Oe)	--	--	5206,69	15537,93	956,73	3013,44	1916,48	25936,07	1461,03	1638,57	649,12	1400,66	698,41	1757,02
n	--	--	1,47	1,71	1,09	1,29	1,36	1,90	1,35	1,53	1,29	1,21	1,34	1,53

J_c (A/mm^2) as a function of T_p(K), x and heat treatment of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$.



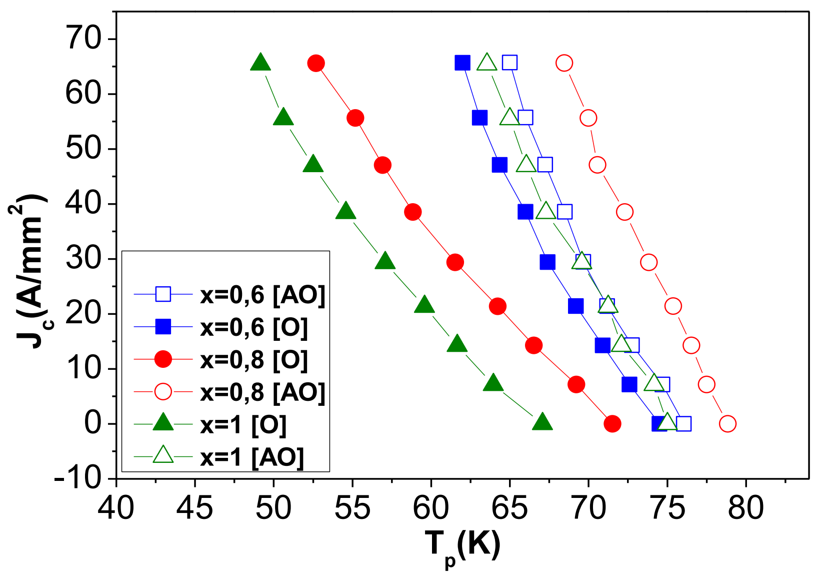
Using the Bean's critical state model

$J_c = H_{dc}/(a*b)^2$

and

$J_c = (1 - T_p/T_c)^n$

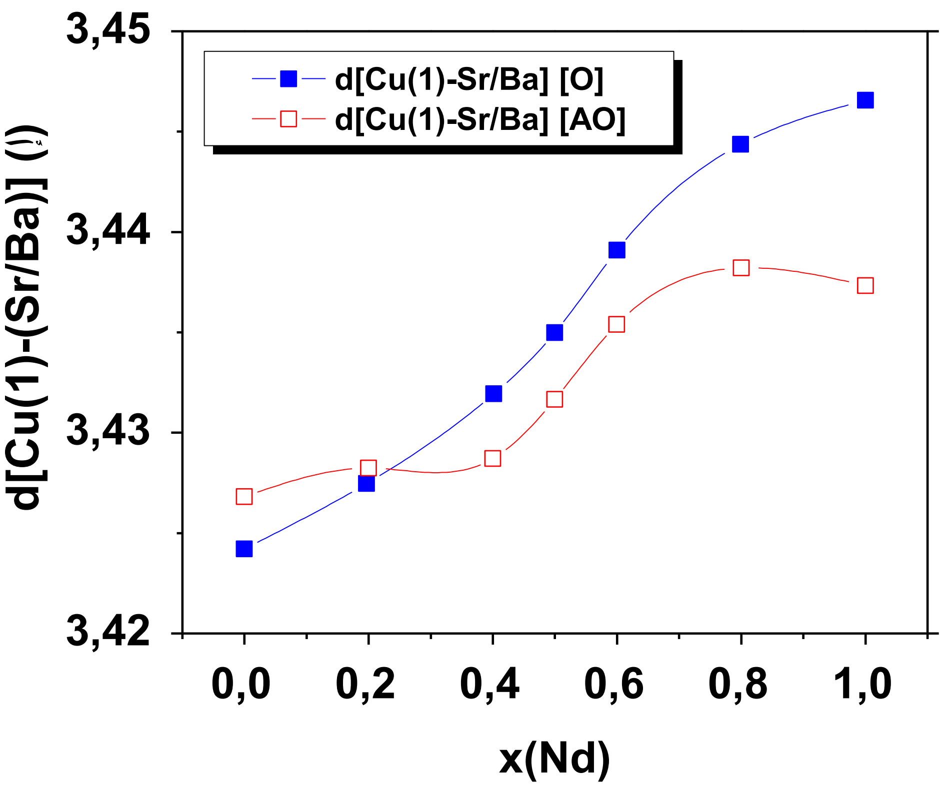
1,5 <n<2: SIS

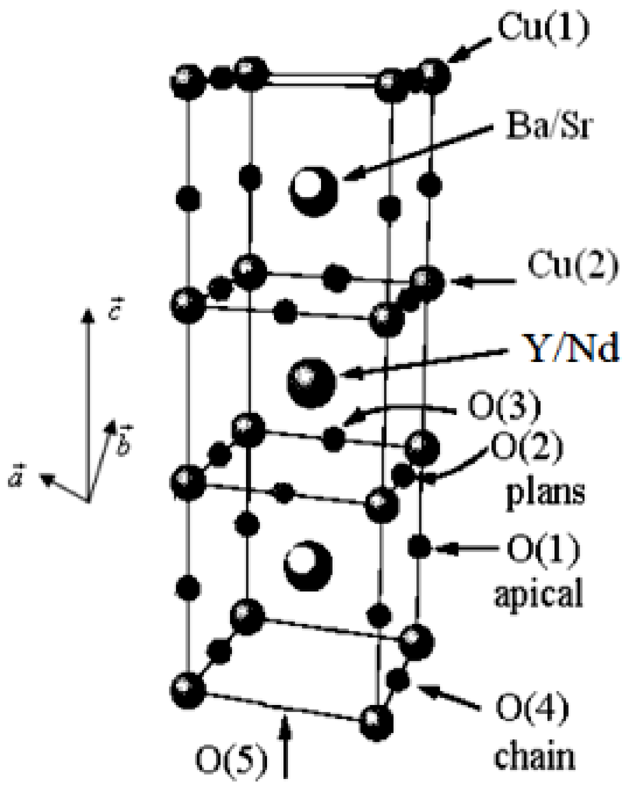


For each x, the [AO] heat treatment :

- **increases J_c**
- **improvement of the quality of the grains and intergranular coupling**

Interatomic distance d[Cu(1)-(Sr/Ba)] as a function of x and heat treatment in $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$.

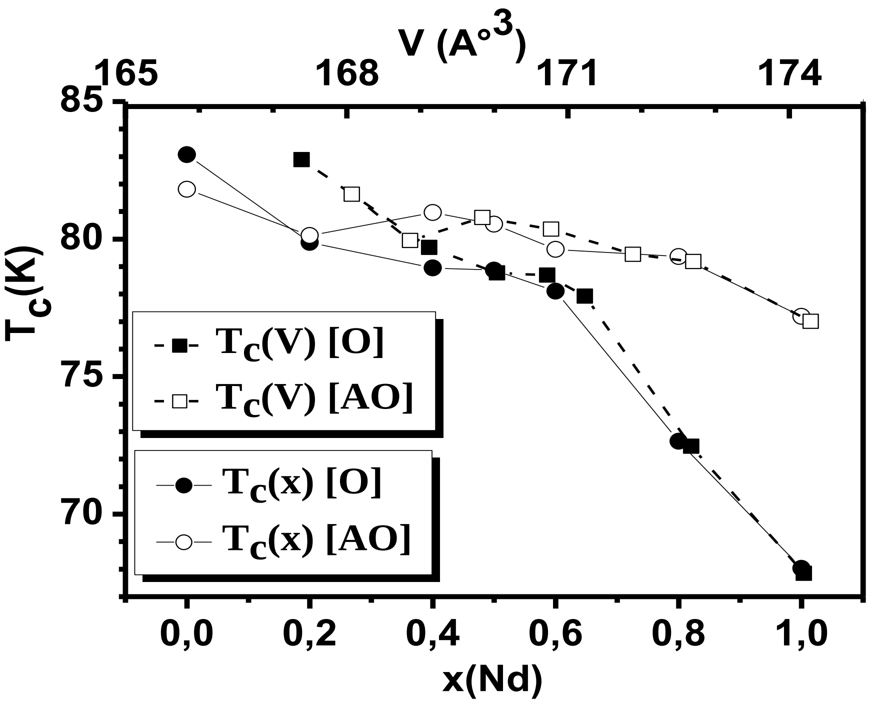


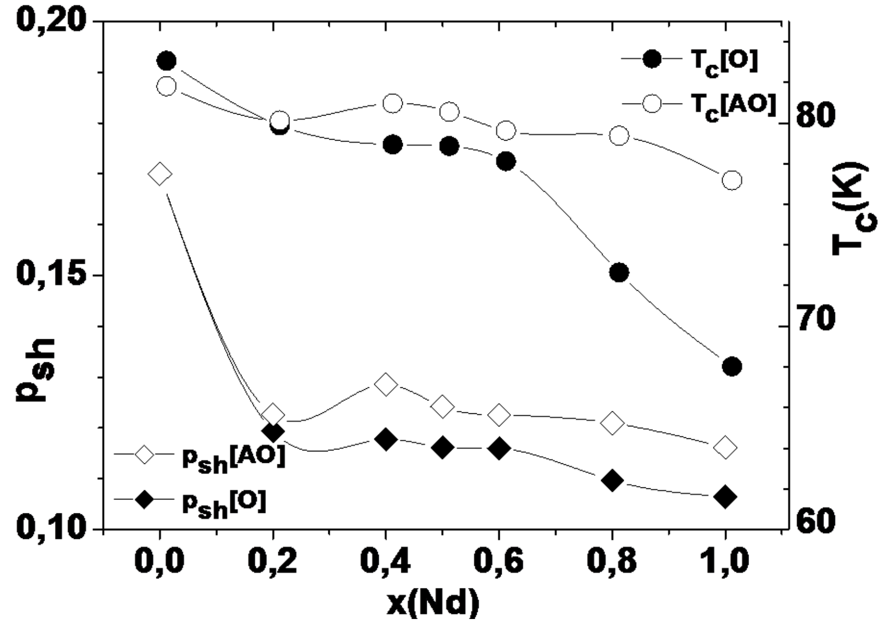


[AO] heat treatment

* Increases d[Cu(1)-(Sr/Ba)] for x<0.25
* Decrease d[Cu(1)-(Sr/Ba)] for x> 0.25 : increases Tc

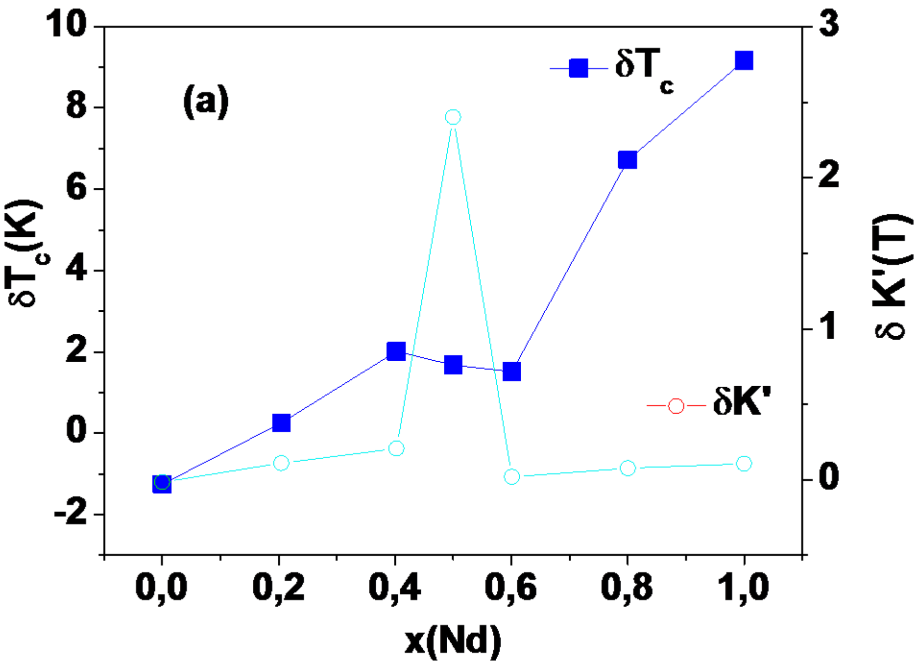
Remarkable correlations between structural, electrical and superconducting properties

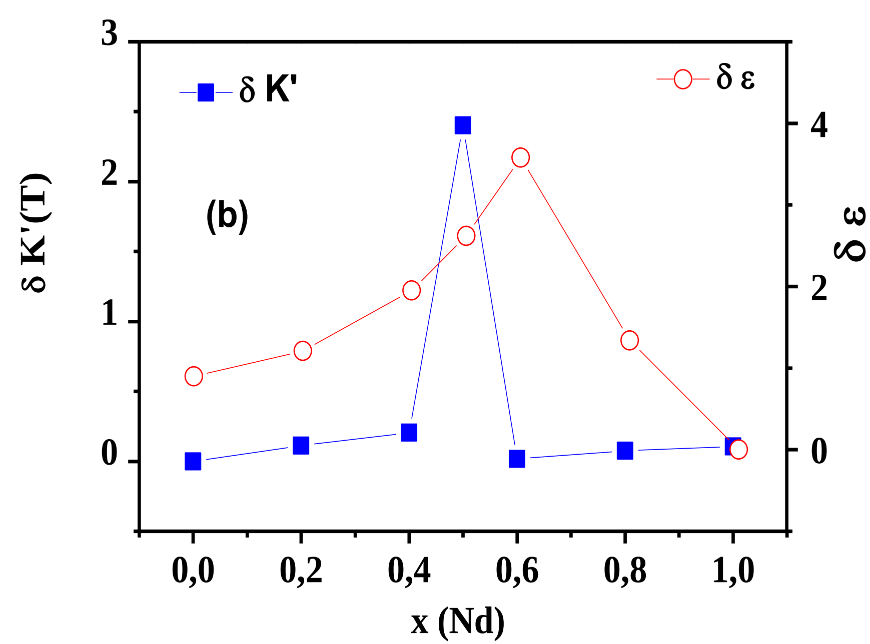




Correlation between Psh with Tc and T_c with V(A°3)
as a function of x and heat treatment of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$.

Remarkable correlations between structural, <u>magnetic</u> and superconducting properties





Correlation between:

- (a) $\delta T_c = T_c[AO] - T_c[O]$ and $\delta K'$
- (b) $\delta\varepsilon$ and $\delta K'$

as a function of x and heat treatment of $Y_{1-x}Nd_xSrBaCu_3O_{6+z}$.

CONCLUSION

The present studies indicate a simple heat treatment procedure to optimize superconducting properties of the high T_c superconductor $(Y_{1-x}Nd_x)SrBaCu_3O_{6+z}$.

In the samples [AO], the remarkable improvement in the irreversibility line and the critical current density J_c are explained by the improvement of the quality of the grains and intergranular coupling and the pinning properties, respectively, as a result of the improvement of crystallographic quality of these samples.

The structural and superconducting properties are correlated with the effect of argon heat treatment.

These results are the outcome of interplay between cationic disorder along the c axis and oxygen disorder in basal plane.

A combination of several factors such as:
* decrease in d[Cu(1)-(Sr/Ba)] for x> 0.2;
* increase
  - in cationic and chain oxygen ordering;
  - p_{sh} and
  - in-phase purity for the [AO] samples

may account for the observed data.

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Thank You For Your Attention