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Study of Suppression of SC gap and 340 cm^{-1} Phonon in $YBa_2Cu_3O_7/La_{2/3}Ca_{1/3}MnO_3$ Superlattices

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Abstract:

The main aim of this paper is to study the factors which effect on the B_{1g} mode phonon of YBCO at the interface between the antagonistic materials YBCO and LCMO. Raman light scattering is the technique which used to perform this work. The Superlattices which studied are thin films of $YBa_2Cu_3O_7/La_{2/3}Ca_{1/3}MnO_3$ with different thickness. This study appears the shrinking of the SC-gap throw the 340 cm^{-1} due to the effect of the LCMO electrons which go through the YBCO and causes breaking of copper pairs, therefore it seems that the YBCO goes from the optimal doped case to the under doped case and that suppress the SC gap

Keywords: Superconducting (SC) gap, 340 cm^{-1} phonon, Superlattices.

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الملخص

تهدف هذه الورقة البحثية لدراسة العوامل المؤثرة على الفونون B_{1g} الخاص بالمادة الموصلة الفائقة YBCO عند السطح الفاصل بين المواد المتضادة في الخواص وهي YBCO و LCMO. تقنية رامان لإستطارة الضوء هي التقنية المستخدمة في إنجاز هذا العمل. الشبكات الفائقة المستخدمة هي عبارة عن أفلام رقيقة من $YBa_2Cu_3O_7/La_{2/3}Ca_{1/3}MnO_3$ مع سمك مختلفة ل YBCO في كل مرة مع ثبات سمك طبقة LCMO. هذه الورقة العلمية تظهر تقلص في فجوة الطاقة من خلال الفونون 340 m^{-1} نتيجة التأثير الناتج من الكترونات المادة LCMO والتي تخترق المادة YBCO وتسبب تكسير في ثنائيات كوبر, وعليه فإنه يظهر تحول المادة YBCO من حالة مثالية التطعيم ذات الموصلية المثالية الفائقة إلي حالة تحت معدل التطعيم الجيد الأمر الذي يصل بها لتقليص فجوة الطاقة.

الكلمات المفتاحية: فجوة التوصيل الفائق (SC)، الفونون 340 سم-1، الشبكات الفائقة.

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Introduction:

Transition.metal.oxides.display.a.wide.range.of.fascinating.properties.resulting.from.a.subtle.interplay.between.charge,.spin,.orbital.and.structural.degrees.of.freedom..For.instance,.in.manganites,.the.“colossal.magnetoresistance”.phenomenon.arises.from.strong.electron.phonon.coupling.associated.with.Jahn.Teller.distortions.(Millis,.1996,.P2),.while.high.temperature.superconductivity.in.Copper.oxides.is.largely.believed.to.be.caused.by.a.spin.fluctuation.mediated.electron.electron.interaction..In.the.quest.for.novel.material.functionalities,.there.has.been.a.growing.interest.for.“artificial”.structures.such.as.super.lattices,.that.can.exhibit.properties.that.are.not.present.in.either.of.the.constituent.materials.alone..This.approach.also.offers.the.possibility.of.combining.a.priori.antagonistic.properties.in.a.single.system..This.was.for.instance.recently.achieved.in.superlattices.involving.superconducting.YBa2Cu3O7.and.half.metallic.ferromagnet.La2/3Ca1/3MnO3,.at.the.interface.of.which.unusual.properties.(e.g..orbital.reconstruction,.charge.transfer).have.been.emphasized.using.x.ray.magnetic.circular.dichroism.(XMCD).or.neutron.reflectivity..In.these.systems.taken.individually,.some.phonons.modes.are.strongly.coupled.to.the.electronic.and.have.been.widely.used.to.study.the.various.phase.transitions..This.is.forinstance.the.case.in.YBa2Cu3O7.of.the.340cm1.phonon..In.YBa2Cu3O6+x,.the.renormalization.across.the.superconducting.transition.of.the.340cm1.buckling.mode.with.B1g.symmetry.is.directly.coupled.to.the.2Δ..superconducting.gap.amplitude,.allowing.one.of.the.first.estimates.of.this.quantity.(Bakr,.2009,.P(1,8))..In.this.paper,.we.used.Raman.scattering.to.investigate.the.temperature.dependence.of.the.340cm1.mode.in.[(YBa2Cu3O7)dYÅ./(La2/3Ca1/3MnO3)dLÅ.]m.superlattices.as.a.function.of.their.relative.thicknesses.dY/dL.with.n=50.Å,..100.Å,..150.Å,..200.Å,..300.Å,..500.Å,..m=20,..15,..10,..7,..5..We.observe.continuous.changes.of.the.renormalizations.of.the.340.cm1.YBCO.mode,.unravelling.charge.transfer.and.mutual.strain.effects.between.the.two.lattices.

Experiments:

We.have.performed.our.experiments.on.high.quality.YBaCuO/LaCaMnO.superlattices..Our.thin.films.were.deposited.by.pulsed.laser.deposition.(PLD).on.SrTiO3.(100).535.mm2.substrates..The.density.of.the.laser.was.of.about.2.J/cm2..The.substrate.was.kept.at.a.constant.temperature.of.about.730℃During.the.depo.sition.processes,.the.pressure.of.the.deposition.chamber.was.of.about.0.5.mbar..Afterwards.films.were.in.situ.annealed.at.530 ℃ .in.an.oxygen.flow.at.one.bar.for.60.minutes.(Soltan,.2004,.P2)..The.resulting.orientation.of.the.YBCO.unit.cell.in.the.YBCOn/LCMO100.superlattice.is.perpendicular.to.the.STO.substrate..The.superconducting.(SC).and.the.ferromagnetic.(FM).transition.temperatures.of.our.thin.films.were.measured.using.a.superconducting.quantum.interference.device.(SQUID)..The.corresponding.transition.temperatures.are.listed.in.table.(I).

The.Raman.scattering..experiments..were..performed.in.nearly.backscattering.geometry.using.a.T6400.triple.grating.Raman.spectrometer.and.Dilor.XY.triple.grating.Raman.spectrometer.equipped.with.a.charge.coupled.device.(CCD).camera..The.resolution.of.our.spectrometers.was.about.3.cm−1..The.laser.used.in.our.experiments.was.an.Ar+/Kr+.mixed.gas.laser.with.wavelength.514.532.nm..The.power.of.the.incident.laser.was.kept.less.than.2.mW.to.avoid.laser.induced.heating..The.incident.and.scattering.lights.were.always.nearly.parallel.to.the.crys.tallographic.c.axis.of.the.YBCO.layer..Thus,.the.electric.fields.of.the.incident.and.scattered.lights.were.parallel.to.the.ab.plane.of.the.YBCO.layer..In.our.experiment,.the.samples.have.been.placed.at.a.cold.finger.in.He.cooled.cryostat,.connected.to.a.temperature.controller.with.a.temperature.stabilization.better.than.1K..All.spectra.presented.in.this.paper.were.taken.in.the.xx/yy.geometry.where.x.(or.y).denotes.the.polarization.of.the.incident.and.scattered.lights..In.this.configuration,.the.light.couples.to.the.A1g+B1g.excitations.(Bakr,.2009,.P2).

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Table.(1).shows.the.characteristics.of.the.samples.used.in.this.study

Sample	YBCO Thickness	LCMO Thickness	TC	......	
SL1	0	3000..˚A	-	275.K	
SL2	50..˚A	100..˚A	35K	235.K	
SL3	100..˚A	100..A˚	45K	230.K	
SL4	150..˚A	100..˚A	48K	225.K	
SL5	200..˚A	100..˚A	60K	220.K	
SL6	100..˚A	50..˚A	25K	195.K	
SL7	300..˚A	100..˚A	75K	220.K	
SL8	˚	˚	**85K**	**220.K**	

TABLE.I:.A.summary.of.the. properties.of.the.samples.used.in.this .study..The.second.and.third.columns .denote.the.YBCO.and.LCMO.thicknesses,.respectively,.whereas.the.fourth.and.fifth.denote.the.superconducting.and.ferromagnetic.transition.temperatures,.respectively.

Results.and.discussion

The.Raman.spectra.consist.of .sharp.features.(Fig.1),.correspond.to .phonons,.superimposed.on.a.broad.background.of.an.electronic.origin..Since.information.about.the.electronic. background.is.barely.achievable,.we. will.focus.our.discussion.on.the.phononic.Raman.spectra..Fig.1.displays.the.Raman.spectra.of.(YBa2Cu3O7)7./ .(La2/3Ca1/3MnO3)7.superlattice.taken.in.the.xx.(or.yy).symmetry.at.various.temperatures.between.10.K.to.300K,.where.YBCO.is.optimal.doped. and.LCMO.is.ferromagnetic.I.observed.four.sharp.phonon.peaks.at.230.cm−1,.340.cm−1,.440.cm−1,.and.500. cm−1..The.phonon.at.230.cm−1.correspond.predominantly.to.inphase.rotational.vibration.of.the.O1.atoms.in.the.MnO6.octahedra,.whereas.the.340 .cm−1.corresponds.to.the.out.of.phase.vibrations.of.the.planar.YBCO.oxygen.atoms..The.500.cm−1.phonon.may.arise.from.vibrations.of.the.YBCO.apical.oxygen.4.The.broad.band.at .600.cm−1.may.come.from.combined.vibrations.of.the.chain.oxygens.of. YBCO.(Bakr,.2009,.P6).(Iliev,.1998, .P2874).(Limonov,.2000,.P12414).and.of.a.stretching.Mn.O.vibration.of.LCMO.compound.(Irwin,.1999,.P9365).(Pantoja,.2001,.P3748).

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Figure.(1).shows.the.density.(arb.units)

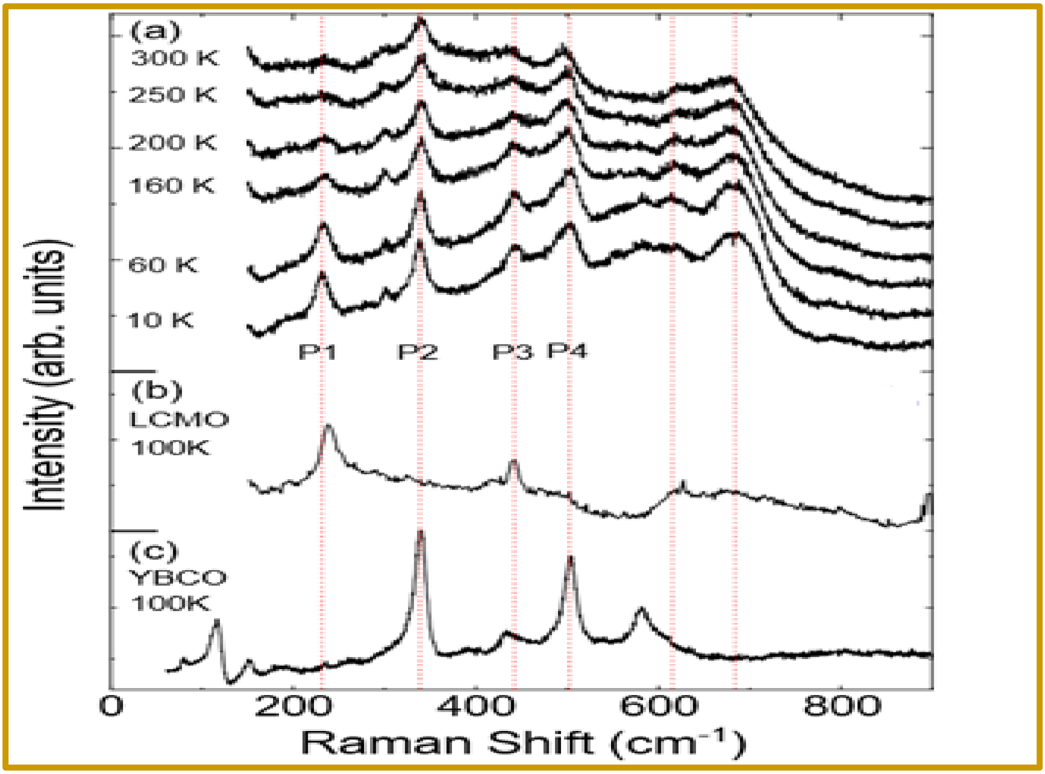

FIG..1:.Raman.spectra.of.YBCO/LCMO.in.the.xx.Raman.channel.taken.with.an.Ar+.laser.line.(λ.=514.532.nm).at.various.temperature..The.mode.assignment.corresponding.to..ref..[Bakr,.2009,.P2].[Irwin,.1999,.P9364]..For.clarify.the.spectra,.vertically.shifted.by.a.constant.offset.with.respect.to.each.other..The.horizontal.ticks.show.the.baseline.of.each.spectrum..P1,.P2,.P3,.and.P4.denoted.atomic.vibrations.of.LCMO.(O1),.YBCO.(out.of.phase.vibration.of.the.planar.oxygen.O2,O3),.YBCO.(in.phase.vibration.of.the.planar.oxygen.O2,O3).and.YBCO.(apical.oxy.gen).

Depending.on.earlier.studies.in.other.similar.oxide.systems.(Bakr,.2009,.P(8,9)).(Bock,1999,.P3535).(Le.Tacon,.2007.,.P5),.the.most.of.phonons.tend.to.be.asymmetric,.i.e..Fano.profiles.

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.In.this.study.we.have.analyzed.all.phonons.using.the.Fano.profile.Formule.which.is.I(ω).=.A[(q.+.ε)2/(1.+.ε2)],.where.ε.=.(ω.ω0)/Γ,.ω0.and.Γ.are.the.phonon.frequency.and.linewidth.(HWHM),.respectively..A.is.a.proportionality.constant.and.q.is.the.Fano.asymmetry.parameter.(Bakr,.2009,.P(8,9)).(Bock,1999,.P3535)..Fig..2.shows.the.resulting.fits.(solid.lines).to.the.experimental.data.(open.circles)..The.fitted.profiles.agree.well.with.the.measured.line.shapes.of.the.340.cm-1.B1g.phonon.mode.

Figure.(2).shows.the.density.(arb.units)

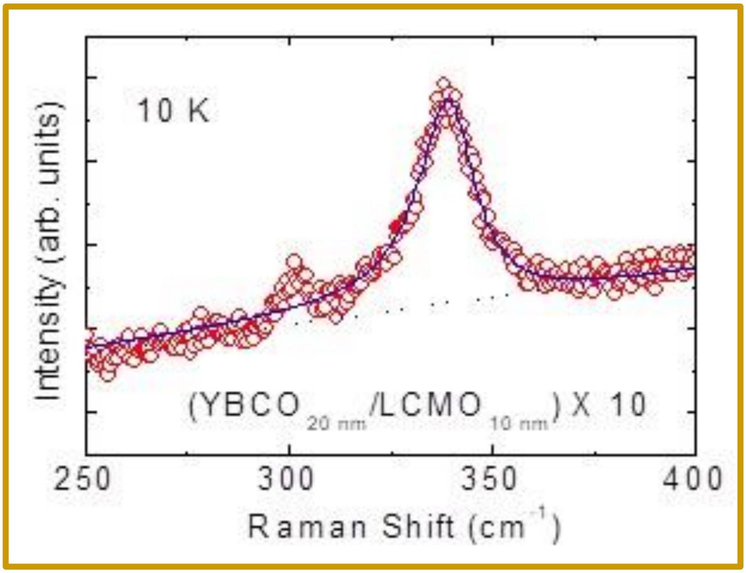

FIG..2:.Fano.profile.analysis.of..Raman.spectra..of..a..YBCO/LCMO..superlattic.of.the.340.cm1.phonon.mode..(λ=514.532.nm).at.T.=10.K..The.red.circles.show.the.experimental.data.where.the.blue.solid.curve.the.fitting.

In.this.article.we.focus.on.the.temperature.evolution.of.the.340.c1.phonon.mode.(Fig..3).observed.for.the.samples.listed.in.table.I..As.observed.in.fig..3a.e,.a.sudden.anomaly.in.the.phonon.frequency.is.observed.at.around.the.superconducting.transition..This.anomaly.is.commonly.related.t

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o.changes.in.the.electronic.system.due.to.the.opening.of.the.superconducting.(SC).gap.(Bakr,.2009,.P(3,8)).(Bock,1999,.P3536).(Devereaux,.1994,.P397)..However,.the.observed.phonon.anomaly.in.the.studied.SLs.appears.to.be.thickness.dependent..That.is,.with.decreasing.the.thickness.of.the.YBCO.layer,.the.anomaly.below.TC.decreases.until.it.vanishes.at.around.dY./dL.=1.5..This.can.be.indeed.seen.in.[inset.in.Fig..3b].

$$\Delta(\omega) = \omega(T) - \omega(T_C)$$

The.thickness.dependence.of.the.superconductivity.induced.anomaly.in..the.frequency.of.the.340.cm−1.phonon.is.summarized.in.the.inset.of.Fig..3c.with.the.data.fitted.using.the.relation

$$\Delta\omega_{SC} = C_1 + C_2 . EXP^{\frac{dY}{dL}}$$

The.best.fit.has.been.obtained.for.the.fit.constants.C1.and.C2.of.about.-2.267.and.9.807,.respectively.

Figure.(3).shows.Frequency.(cm-1).

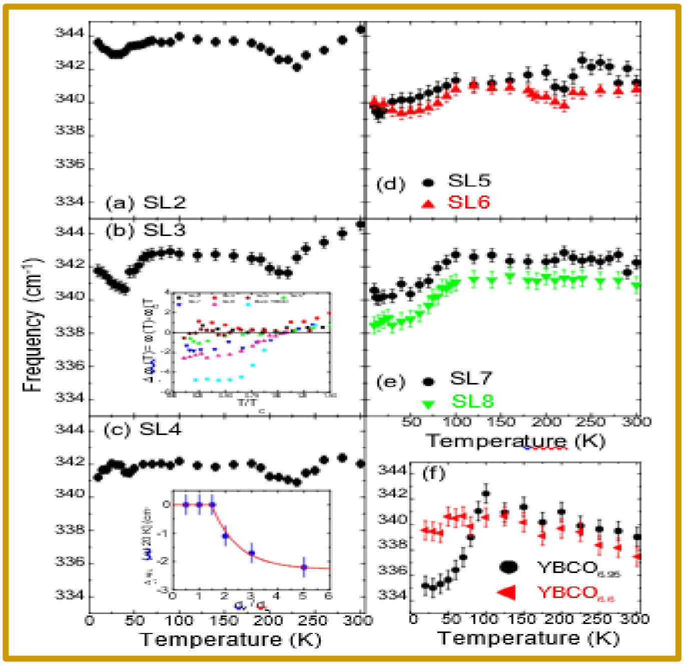

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FIG..3:.(ae).Temperature.dependence.of.the.340.cm−1.phonon.frequency.of.the.samples.studied.here..(f).Temperature.dependence.of.the.340.cm−1.phonon.frequency.of.bulk.YBCO6.95.(circles).and.YBCO6.6.(triangles).taken.from.Refs.[Bakr,.2009, P(7,9)].

The.decrease.in.the.340.cm−1.Phonon.anomaly.below.TC.is.analogs.to.that.observed.in.pure.YBCO6+x.system.(Fig.3f),.where.the.decrease.in.phonon.anomaly..in.the.latter.system.may.arise.from.shrinking.the.superconducting.gap.with.underdoping.(Le.Tacon,.2007,.P(45).(Limonov,.2000,.P3)..In.our.superlattice.systems,.the.decrease.in.the.340.cm−1.phonon.(B1g.mode).anomaly.below.TC,.may.come.from.the.decrease.in.the.superconducting.gap.due.to.the.spin.self-diffusion.(or,.equivalently.inverse.proximity.effect).(Soltan,.2004,.P(1,4)),.in.which.the.immigrant.electronic.spins.from.LCMO.to.YBCO.layer.break.the.cooper.pairs.in.the.latter.and.decrease.the.SC.gap..This.scenario.is.further.supported.by.the.apparent.correspondence.of.the.spin.diffusion.length. $\xi FM 100$Å.(Soltan,.2004,.P1).and.the.thickness.at.which.the.phonon.anomaly.vanishes.(inset.in.Fig..3b)

Conclusion:

Depending.on.all.results.I.got.and.what.I.already.observed.and.discussed.I.could.conclude,.that.taking.all.the.experimental.results.together,.I.can.confirm.that.the.suppression.of.the.SC.state.which.we.see.in.Fig..3.is.due.to.doping.of.electrons.into.YBCO.from.the.LCMO.layer..To.quantify.this,.using.the.TC.data.from.the.films.together.with.data.from.the.bulk.(Liang,.2006,.P(23)).(Gray,.2016,.P5).(Tabis,.2014,.4).Fig..3(f),.we.can.estimate.that.each.LCMO.layer.is.doping.0.67.electrons.to.the.whole.of.the.YBCO.layer,.but.only.∼.0.05.electrons.into.the.CuO2.planes.as.shown.in.Fig..4..This.discrepancy.is.perhaps.not.surprising.though.since.in.the.bulk.changing.from.YBa2Cu3O7.to.YBa2Cu3O6,.which.is.a.total.charge.change.of.2.only.leads.to.a.small.doping.change.in.the.CuO2.plane.(Limonov,.2000,.P3).(Liang,.2006,.P2).(Gray,.2016,.P(2,5)).and.the.same.thing.will.occur.to.all.superlattices.which.we.have.measured..Therefore,.we.can.say

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.the.doping.of.YBCO.has.been.changed.from.optimal.doped.to.under.doped.due.to.electrons.leak.which.occurs.due.to.the.neighbor.layers.of.LCOM.

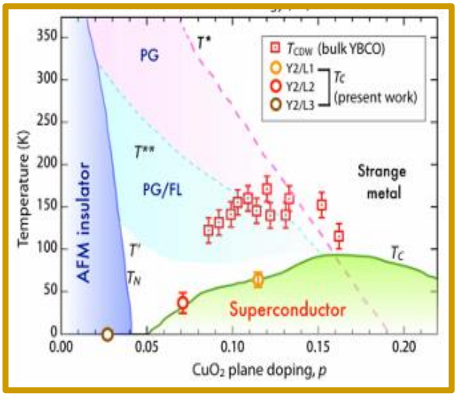

Fig..4:.Doping.level.inferred.from.both.Tc.and.the.XAS.analysis.of.Y2/LN.SLs.are.overlayed.with.the.bulk.phase.diagram.for.YBCO.[Gray,.2016,.P5]..PG.=.pseudogap,.FL=Fermi.liquid..Superconducting.TC.is.defined.as.the.midpoint.of.the.transition.and.the.width.of.transition.has.been.marked.as.the.corresponding.error.bar.

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