



Afaq Journal for Human
and Applied Studies

Faculty of Arts and Sciences
ALAbyar University of Benghazi

ISSUE: **2** – August **2024**

مجلة آفاق للدراسات
الإنسانية والتطبيقية
كلية الآداب والعلوم الإيبار
جامعة بنغازي
العدد: الثاني – أغسطس 2024



Study of Suppression of SC gap and 340 cm^{-1} Phonon in $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$ Superlattices

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DOI: <https://doi.org/10.37376/ajhas.vi2.6866>

Received: 29.05.2024

Accepted: 08.06.2024

Published: 16.08.2024

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 $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$ 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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د. نادر عمر مسعود إدريزه

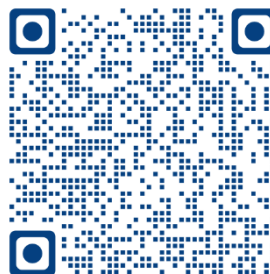
1. محاضر بقسم الفيزياء كلية الآداب والعلوم المرج.

المخلص

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 $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$ 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 إلى حالة تحت معدل التطعيم الجيد الأمر الذي يصل بها لتقليل فجوة الطاقة.

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

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E-ISSN 3007-4495

ISSN-L 3007-4495

Legal Deposit Number 313/2023

DOI <https://doi.org/10.37376/ajhas.vi2>

Frequency: Two Issues per year

Publication Fees are Free

Publisher: University of Benghazi, Benghazi, Libya

Editor-in-Chief Prof. Mohamed Lama

<https://journals.uob.edu.ly/AJHAS>

ajhas.journal@uob.edu.ly

+218924809776



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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 superlattices, 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 $\text{YBa}_2\text{Cu}_3\text{O}_7$ and half-metallic ferromagnet $\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$, 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 phonon modes are strongly coupled to the electronic and have been widely used to study the various phase transitions. This is for instance the case in $\text{YBa}_2\text{Cu}_3\text{O}_7$ of the 340 cm^{-1} phonon. In $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$, the renormalization across the superconducting transition of the 340 cm^{-1} buckling mode with B_{1g} 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 340 cm^{-1} mode in $[(\text{YBa}_2\text{Cu}_3\text{O}_7)_d(\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3)_d]_m$ superlattices as a function of their relative thicknesses dY/dL with $n=50, \dots, 100, \dots, 150, \dots, 200, \dots, 300, \dots, 500, \dots, m=20, \dots, 15, \dots, 10, \dots, 7, \dots, 5$. We observe continuous changes of the renormalizations of the 340 cm^{-1} YBCO mode, unravelling charge transfer and mutual strain effects between the two lattices.



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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 about 2 J/cm². The substrate was kept at a constant temperature of about 730 °C. During the deposition process, the pressure of the deposition chamber was about 0.5 mbar. Afterwards, films were in situ annealed at 530 °C in an oxygen flow at one bar for 60 minutes (Soltan, 2004, P2). The resulting orientation of the YBCO unit cell in the YBCO/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 crystallographic 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 1 K. 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 A_{1g}+B_{1g} excitations (Bakr, 2009, P2).

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.fourh.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.3

00K,.where.YBCO.is.optimal.doped.and.LCMO.is.ferromagnetic.I.observ ed.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.primarily.to.inphase.rotational.vibration.of.the.O1.atoms.in.the.MnO₆octahedra,.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.combine d.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).

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

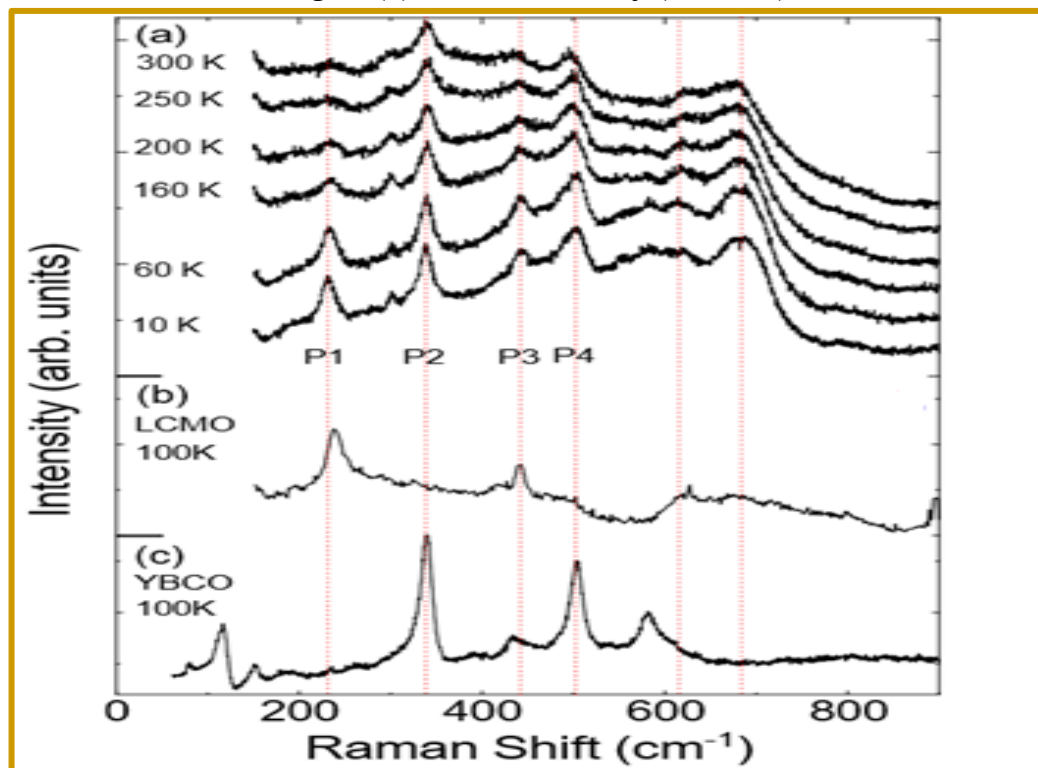


FIG..1:.Raman.spectra.of.YB
CO/LCMO.in.the.xx.Raman.channel.
taken.with.an.Ar+.laser.line.(λ =514.
532.nm).at.various.temperature..The
mode.assignment.corresponding.to..r
ef..[Bakr,.2009,.P2].[Irwin,.1999,.P9
364]..For.clarify.the.spectra,.verticall
y.shifted.by.a.constant.offset.with.res
pect.to.each.other..The.horizontal.tic
ks.show.the.baseline.of.each.spectru
m..P1,.P2,.P3,.and.P4.denoted.atomi

c.vibrations.of.LCMO.(O1),.YBCO.(
out.of.phase.vibration.of.the.planar.o
xygen.O2,O3),.YBCO.(in.phase.vibr
ation.of.the.planar.oxygen.O2,O3).an
d.YBCO.(apical.oxy.gen).

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

.In.this.study.we.have.analyz ed.all.phonons.using.the.Fano.profile .Formule.which.is. $I(\omega)=A[(q+. \varepsilon)^2/(1+. \varepsilon^2)]$,.where. $\varepsilon=(\omega-\omega_0)/\Gamma$,. ω_0 .an d. Γ .are.the.phonon.frequency.and.lin ewidth.(HWHM),.respectively..A.is. a.proportionality.constant.and.q.is.th

e.Fano.asymmetry.parameter.(Bakr,. 2009,.P(8,9)).(Bock,1999,.P3535)..Fi g..2.shows.the.resulting.fits.(solid.lin es).to.the.experimental.data.(open.cir cles)..The.fitted.profiles.agree.well.w ith.the.measured.line.shapes.of.the.3 40.cm-1.B1g.phonon.mode.

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

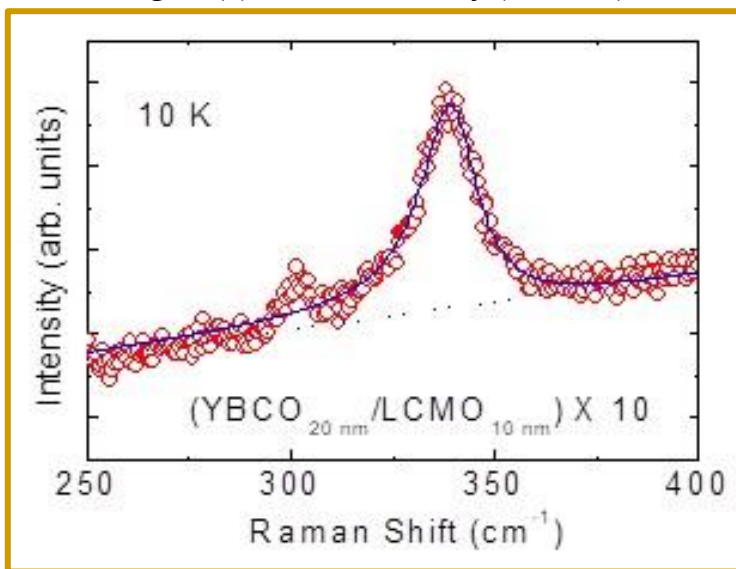


FIG..2:.Fano.profile.analysis. of..Raman.spectra..of..a..YBCO/LC MO..superlattice.of.the.340.cm1.phon on.mode..($\lambda=514.532$.nm).at.T.=10. K..The.red.circles.show.the.experime ntal.data.where.the.blue.solid.curve.t he.fitting.

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

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

$$\Delta\omega_{SC} = C_1 + C_2 \cdot \text{EXP} \frac{dY}{dL}$$

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).

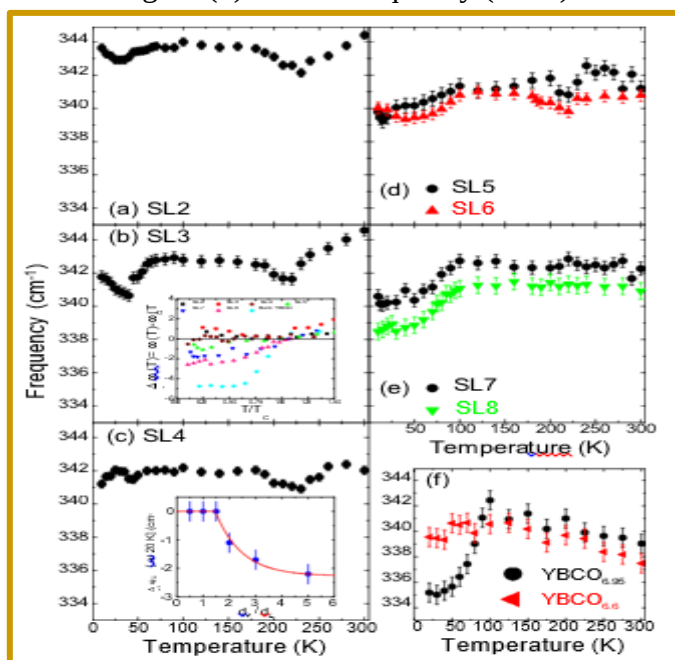




FIG..3:.(ae).Temperature.dep
endence.of.the.340.cm⁻¹.phonon.fre
quency.of.the.samples.studied.here..(f).Temperature.dependence.of.the.340.cm⁻¹.phonon.frequency.of.bulk.YBCO6.95.(circles).and.YBCO6.6.(triangles).taken.from.Refs.[Bakr,,2009,P(7,9)].

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

ξFM100Å.(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

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

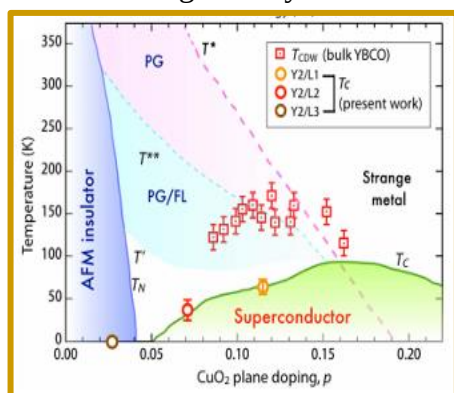


Fig.4.:Doping.level.inferred.
from.both.Tc.and.the.XAS.analysis.o
f.Y2/LN.SLs.are.overlayed.with.the.
bulk.phase.diagram.for.YBCO.[Gray
,2016,P5]..PG.=.pseudogap,FL=Fermi.liquid..Superconducting.TC.is.de
fined.as.the.midpoint.of.the.transitio
n.and.the.width.of.transition.has.been
.marked.as.the.corresponding.error.b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

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الإنسانية والتطبيقية
كلية الآداب والعلوم الإيبأر
جامعة بنغازي

العدد: الثاني — أغسطس 2024



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