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SOUND VELOCITY IN Zn SUBSTITUTED $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ SUPERCONDUCTOR

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ABSTRACT

Ultrasonic longitudinal and shear velocities were measured in superconducting $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ (x = 0, 0.01, 0.05) at 5-10 MHz between 80 K and 300 K. The characteristic Debye temperature was determined and the electron-phonon coupling constant was calculated using the BCS theory in the weak coupling limit and the van Hove scenario. The variation in the elastic behaviors upon Zn doping is attributed to the effect of changes in the spin correlation at the CuO_2 planes due to Zn doping.

INTRODUCTION

Electron-phonon coupling strongly influences the electronic properties of high temperature superconductors (HTSCs) and must be included in any microscopic theories. It is generally known that the CuO_2 planes play a major role in the electronic properties of layered cuprate superconductors. Substitution of non-magnetic impurities such as Zn should have a significant effect on the electronic properties of these d-wave superconductors [1]. It is interesting to investigate further the effect of Zn on the elastic and ultrasonic properties of cuprate superconductors.

Previous reports on the ultrasonic properties of $HoBa_2Cu_3O_{7-\delta}$ study the effect of Ho substitution on the Ba site [2]. In this work, we report results of longitudinal and shear ultrasonic wave velocities measurement in $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ (x = 0, 0.01, 0.05). The electron-phonon coupling constants are estimated using the standard BCS theory and the van Hove scenario. Powder X-ray diffraction and scanning electron microscope (SEM) investigations are also reported.

EXPERIMENTAL DETAILS

The $HoBa_2Cu_{3-x}Zn_xO_{7-\delta}$ (x = 0, 0.01, 0.05) samples were prepared via standard solid state synthesis using high purity ($\geq$ 99.9%) powders of Ho_2O_3, BaO, CuO and ZnO. The electrical resistance of the pellets was measured using the four point probe technique with silver paint contacts. The samples were also examined by X-ray powder diffraction with CuK_α radiation using Siemens D5000 diffractometer. The microstructure of the samples was recorded using a Philips XL 30 scanning electron microscope (SEM).

The ultrasonic velocity was measured using a Matec 7700 system, which utilizes the pulse-echo-overlap technique. The sample was bonded to the transducer using Nonaq stopcock grease. The ultrasonic waves were propagated along the direction of

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pressing using an X-cut (longitudinal) or Y-cut (shear) quartz transducer with a fundamental frequency of 10 MHz. The measurements were performed in an Oxford Instruments liquid nitrogen cryostat, model DN 1711 and the temperature was changed at a rate of about 1 K min^{-1} during warming and cooling. No thermal expansion correction was made.

RESULTS AND DISCUSSIONS

Powder X-ray diffraction pattern showed all samples to be single-phased and orthorhombic as shown in Figure 1. The temperature dependent electrical resistance of $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ (x = 0, 0.01, 0.05) showed metallic normal state behavior and superconducting transition T_{conset} (onset critical temperature) of 90, 88 and 58 K for x = 0, 0.01, 0.05 respectively , as shown in Figure 2. The T_c decreased with Zn substitution due to Zn^{2+} (non-magnetic impurities) disrupts the local antiferromagnetic correlation of Cu atom [1]. No significant variation in microstructures was observed by SEM between all the samples in Figure 3. The transition temperature, longitudinal and shear velocities, Debye temperature measured at 80 K, electron-phonon coupling constant, λ calculated using BCS theory [3] ($T_c = 1.13\theta_D e^{-1/\lambda}$) and two-dimensional van Hove scenario [4] with $T_C = 272\theta_D e^{-1/\sqrt{\lambda}}$ are given in Table 1 [3,4]. The differences in the elastic behavior between samples are most probably not related to the average grain size and porosity since no significant variations in the microstructure are observed in SEM micrographs. A hysteresis loop possible indicating Zn substitution effect was observed between 112 K and 214 K in longitudinal velocity for the $HoBa_2(Cu_{2.99}Zn_{0.01})O_{7-\delta}$ (Figure 5(b)) but no velocity hysteresis was observed in shear mode. A steep longitudinal velocity change was observed near 280 K in the non-Zn added sample. This anomaly is attributed to the oxygen-ordering phenomenon [5], which is suppressed in Zn added samples.

We have not determined the oxygen content of the samples directly. However, the oxygen content is assumed to be invariant because the preparation condition is the same for all samples. In addition, there is no variation in the (013), (101) and (103) peaks in the XRD patterns which indirectly show that the oxygen content is invariant in all samples.

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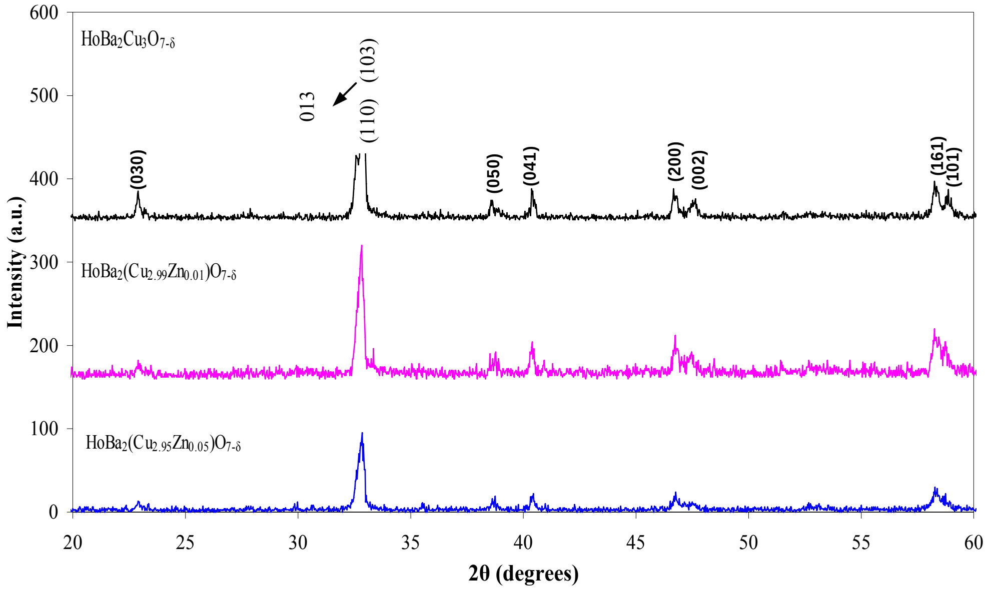

Figure 1: X-ray diffraction of $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ (x = 0.0, 0.01, 0.05)

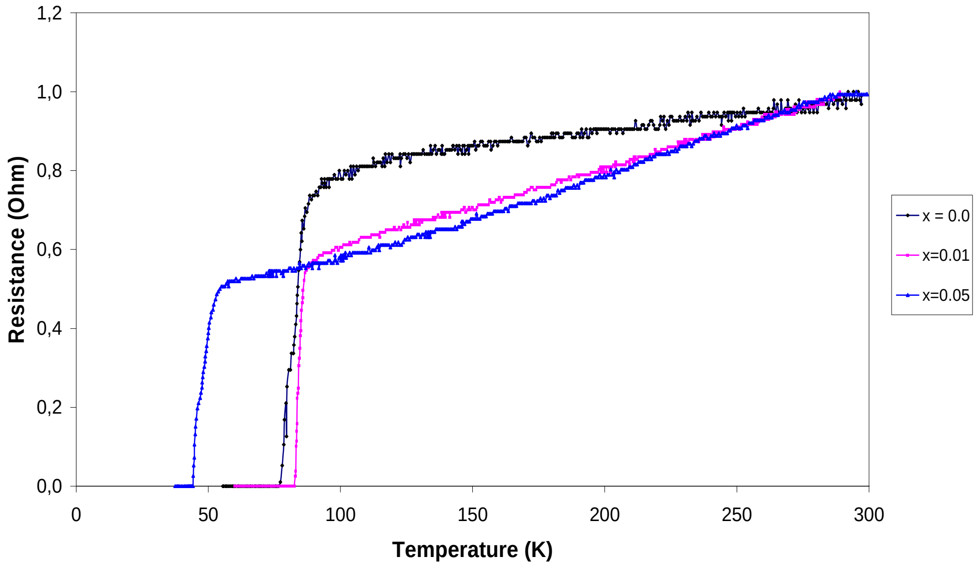

Figure 2: Temperature dependent electrical resistance of $HoBa_2(Cu_{3-x}Zn_x)O_{7-\delta}$ (x = 0.0, 0.01, 0.05)

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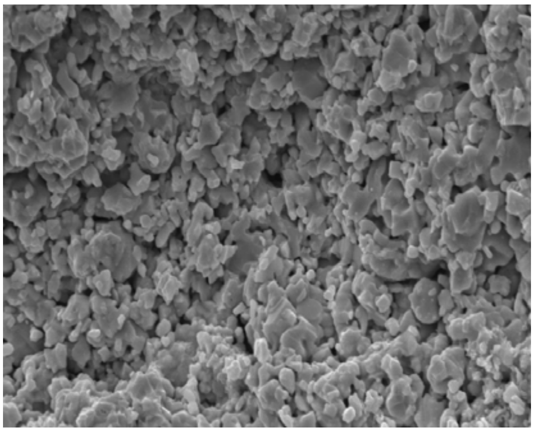
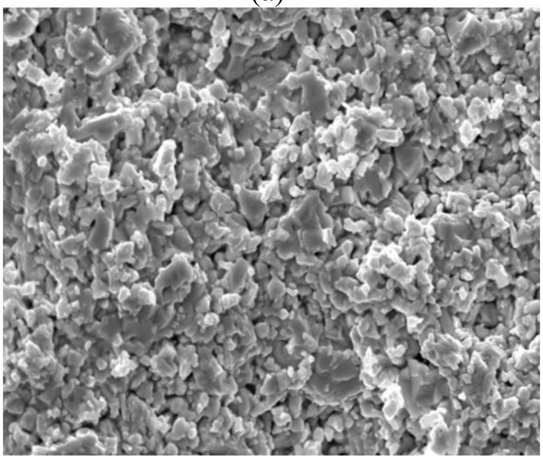
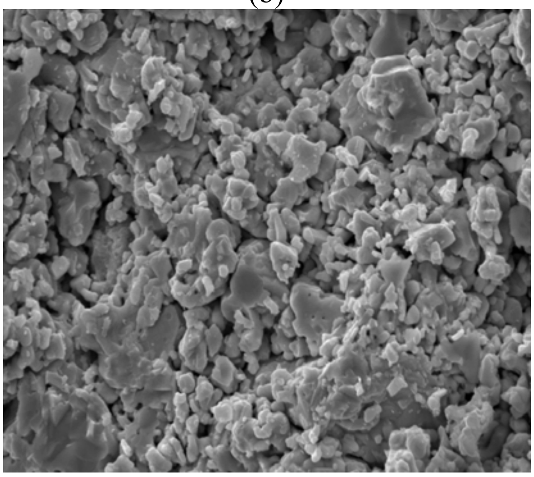


(a)



(b)



(c)

Figure 3: Scanning electron micrograph of (a)$HoBa_2Cu_3O_{7-\delta}$ (b)$HoBa_2(Cu_{2.99}Zn_{0.01})O_{7-\delta}$ and (c) $HoBa_2(Cu_{2.95}Zn_{0.05})O_{7-\delta}$

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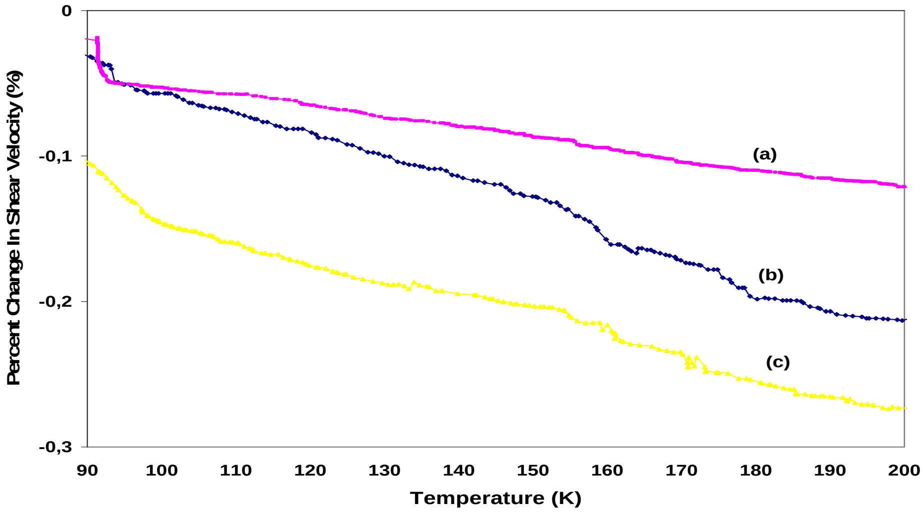
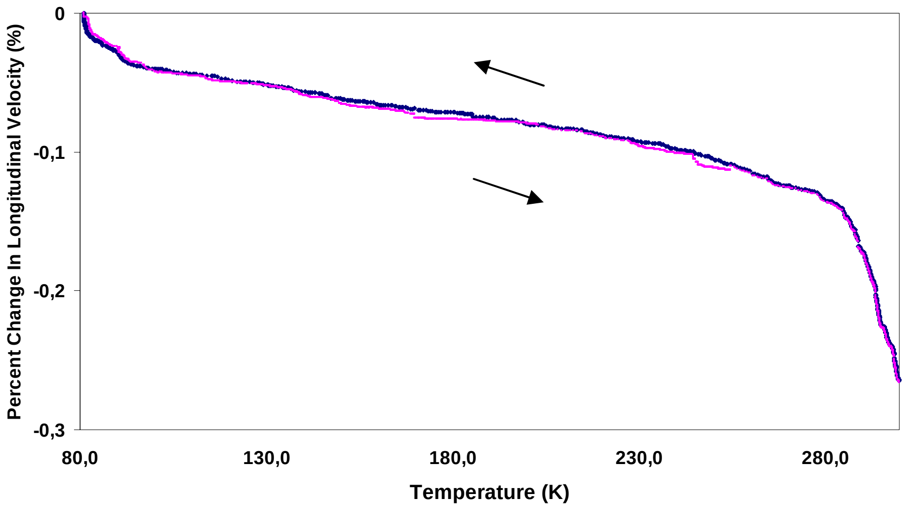


Figure 4: Temperature dependence of the shear velocity for (a) $HoBa_2Cu_3O_{7-\delta}$, (b)$HoBa_2(Cu_{2.99}Zn_{0.01})O_{7-\delta}$ and (c) $HoBa_2(Cu_{2.95}Zn_{0.05})O_{7-\delta}$



(a)

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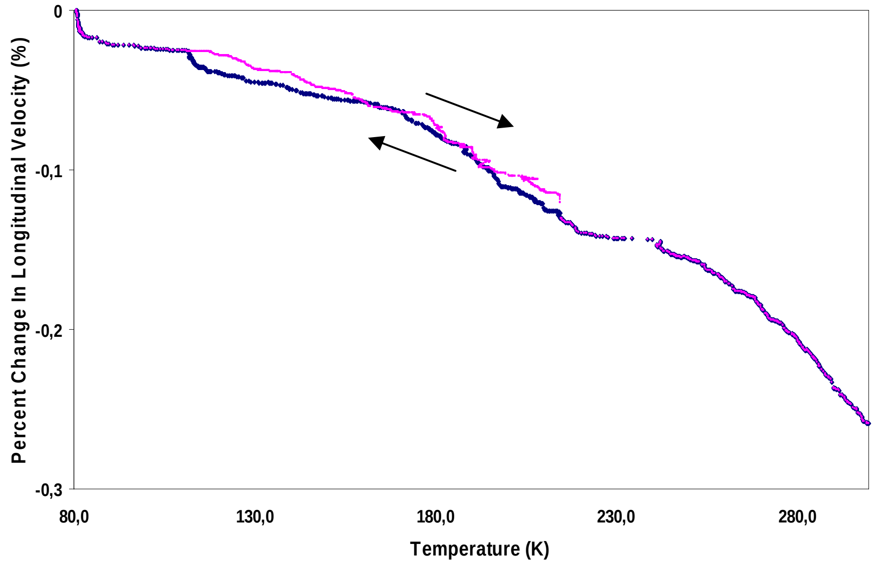

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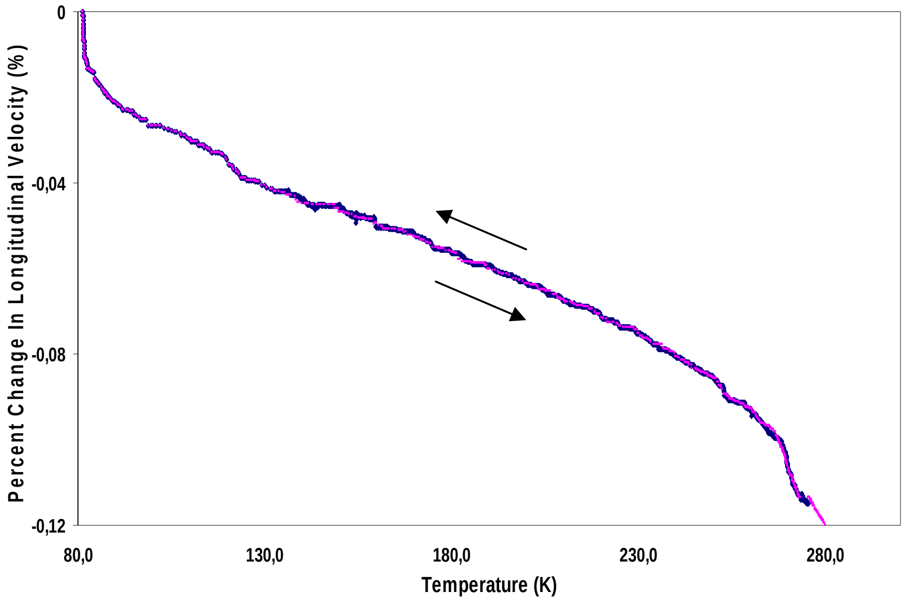

(c)

Figure 5: Temperature dependence of the longitudinal velocity for (a) $HoBa_2Cu_3O_{7-\delta}$, (b) $HoBa_2(Cu_{2.99}Zn_{0.01})O_{7-\delta}$ and (c) $HoBa_2(Cu_{2.95}Zn_{0.05})O_{7-\delta}$

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Table 1: Transition temperature (T_c), longitudinal velocity (v_l) and shear velocities (v_s), Debye temperature (θ_D) measured at 80 K, electron-phonon coupling constant, (λ_{BCS}) and two-dimensional van Hove scenario (λ_{Hove}). The values in brackets are not corrected for voids in the sample.

Sample (x)	Density (g/cm^3)	T_c (K)	v_l (ms^{-1})	v_s (ms^{-1})	θ_D (K)	λ_{BCS}	λ_{Hove}
0	7.49	90	5065	4029	535	0.53	0.04
	(4.14)		(4368)	(3839)	(407)	(0.61)	(0.04)
0.01	7.73	88	5226	2969	531	0.52	0.04
	(3.98)		(3750)	(3775)	(381)	(0.63)	(0.04)
0.05	7.94	58	7016	4894	563	0.42	0.03
	(4.05)		(6438)	(4543)	(473)	(0.45)	(0.03)

In conclusion, the transition temperature decreases with increasing Zn content. However the Debye temperature decreased at x = 0.01 and increased at x = 0.05. This variation may be attributed to the spin correlation of the CuO_2 planes, which affects the electron-phonon interaction. The steep longitudinal velocity change observed in the non-Zn added sample is attributed to oxygen-ordering processes, which was suppressed in the Zn added samples. The van Hove electron-phonon coupling constant is an order of magnitude lower than the BCS electron-phonon coupling. Further work is necessary to determine directly the electron-phonon coupling constant in these materials.

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