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PREPARATION AND PROPERTIES OF  $La_{2-x}A_xCuO_{4-y}$  Where A = Pb,Cd

by

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*Copper oxides  
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PREPARATION AND PROPERTIES OF  $\text{La}_{2-x}\text{A}_x\text{CuO}_{4-y}$  Where A = Pb, Cd

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ABSTRACT

The substitution of lead and cadmium for lanthanum in  $\text{La}_2\text{CuO}_4$  was studied and the limits of solubility were established. Single phase compositions were characterized and their physical properties were correlated with the substitution of bismuth and are interpreted on the basis of a model proposed by Goodenough.

Introduction

In a previous study (1), it was shown that small substitutions of bismuth for lanthanum resulted in an increase in the delocalization of carriers as the bismuth content was increased. All of the samples showed p-type conductivity. This was found to be consistent with a model proposed by Goodenough (2, 3) in which antiferromagnetic behavior gives rise to correlation splitting of the  $\sigma^*$  band. The  $\sigma^*$  upband is essentially empty, but the observed p-type character of  $\text{La}_{2-x}\text{Bi}_x\text{CuO}_4$  samples where  $x > 0.08$  is consistent with some hole occupancy of the  $\pi^*$  band.

In an effort to further elucidate the role of A-site substitution on the electronic properties of  $\text{La}_2\text{CuO}_4$ , a study was undertaken to prepare samples in which both lead and cadmium were substituted for A-site lanthanum. There appears to be no report concerning the substitution of cadmium, but Guker et al. (4) indicated that even at a concentration of 5 atomic percent of lead substitution, a pure phase was not formed and the sample showed an activated conductivity. Since their preparations were attempted by direct combination of oxides or carbonates between 1000-1100°C, it is not surprising that pure products were not obtained. The purpose of this study was, therefore, to apply the method of double decomposition of mixed metal nitrates to prepare single-phase compounds with the compositions  $\text{La}_{2-x}\text{A}_x\text{CuO}_4$  (A = Pb, Cd) and to characterize their electronic and magnetic properties.

Experimental

All samples were prepared by dissolving copper metal (5-9's Aesar Chemical Co.),  $\text{PbCO}_3$  (reagent grade, Mallinckrodt) or Cd (5-9's Cominco), and  $\text{La}_2\text{O}_3$  (4-9's Aesar Chemical Co.) in 1:1 dilute nitric acid. The solution was evaporated on a hot plate to dryness, then placed in a furnace and heated to 500°C for 24 hours in order to decompose the nitrates. The product was reground and reheated again for 24 hours at 800°C. After a final grinding, the product was heated for 24 hrs at 950°C and allowed to slow cool in air to room temperature. In order to prepare samples which are oxygen deficient, the

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products were heated in a predried argon atmosphere (flow rate of 50 sccm/min) at 600°C.

#### Characterization of Samples

X-ray powder diffraction patterns were obtained with a Philips-Norelco diffractometer using monochromatic high-intensity  $\text{CuK}\alpha_1$  radiation ( $\lambda = 1.5405\text{\AA}$ ). For the qualitative identification of the phases present, the patterns were taken from  $12^\circ < 2\theta < 72^\circ$  with a scan rate of  $1^\circ 2\theta/\text{min}$  and a chart speed of 30 in/hr. The scan rate used to obtain x-ray patterns for precision cell constant determination was  $0.25^\circ 2\theta/\text{min}$  with a chart speed of 30 in/hr. Cell parameters were determined by a least-squares refinement of the reflections using a computer program which corrects for the systematic errors of the measurement. The total active oxygen content of the samples was determined by the procedure of Ward and Struthers (5). This method allows for the determination of total oxidation of copper, i.e., the amount of formal valence Cu(III) present in the products. Thermogravimetric analysis indicated no loss of copper, lead or cadmium up to the temperature of preparation. Therefore, the compositions of the prepared samples corresponded to the stoichiometries given. Magnetic susceptibility measurements were carried out using a Faraday balance from 77 to 300 K with a field strength of 10.4 kOe. Field dependency measurements were carried out at 77 and 300 K. The van der Pauw method was used to measure the electrical resistivity. Contacts were made by ultrasonically soldering indium directly onto sintered pellets and their ohmic behavior was established by measuring the current-voltage characteristics. Qualitative Seebeck measurements were also made to characterize the carrier type of the samples.

#### Results and Discussion

Polycrystalline samples of the systems  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  and  $\text{La}_{2-x}\text{Cd}_x\text{CuO}_{4-x/2}$  were prepared by decomposition of the appropriate nitrates in air. The limit of substitution of lead for lanthanum was established at  $x = 0.15$ . For the composition where  $x = 0.24$ , there was evidence for the presence of excess  $\text{PbO}$  as determined from x-ray diffraction patterns using a scan rate of  $0.25^\circ 2\theta/\text{min}$  with a chart speed of 30 in/hr. For cadmium substitution the limit was established at  $.05 < x < .02$ .  $\text{CdO}$  appeared in x-ray patterns of the composition  $x = .05$ .

The lattice parameters for members of the lead substituted series are given in Table I and II. It is readily seen that for  $x = 0.2$ , the  $a$  and  $b$  parameters approach each other. However, at this composition, the structure is still orthorhombic. It was shown (1) that for bismuth substitutions at  $x > .08$ , the products were tetragonal. It is apparent that lead does not affect the orthorhombic to tetragonal transition as markedly as bismuth. The degree of substitution of cadmium for lanthanum is too small to change the cell parameters.

The magnetic susceptibility vs temperature measurements were made on members of the series  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  where  $.002 < x < .2$ . The results of these measurements are summarized in Table I and II and Figs. 1 and 3. As the lead content is increased, there is a marked decrease in the observed Néel point and, at  $x \geq .1$ , Pauli paramagnetic behavior is observed. The resistivities of the as-prepared samples are plotted vs  $1000/T$  in Fig. 2. It can readily be seen that the resistivity decreases with increasing lead substitution and the lead substituted samples show metallic behavior. Both the magnetic and electrical measurements indicate that, as observed with the bismuth substituted

system (1), there is an increase in delocalization of carriers with increased lead substitution. The observed p-type character of these materials indicates some hole occupancy of the  $\pi^*$  band. The  $\sigma^*$  band is split and the  $\sigma^*$  upband is essentially empty. When the samples were annealed in argon, an observable increase in the Néel temperature as well as increase in the resistivity was obtained (Figs. 3, 2) for samples where  $x < 0.1$ . For samples where  $x \geq 0.1$ , metallic behavior is still observed. All of the argon annealed samples retained an orthorhombic structure. Attempts to analyze the active oxygen content of all the samples prepared (by iodometric analysis) gave compositions which were close to  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2}$ . However, several of the samples with a lead content greater than 0.1 did show a detectible increase in active oxygen, i.e.  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  where  $\delta \approx 0.02$ .

Samples of  $\text{La}_{2-x}\text{Cd}_x\text{CuO}_{4-y}$  where  $.005 < x \leq .05$  were also prepared by decomposition of mixed nitrates. Since the amount of cadmium which was substituted for lanthanum was small, it was not possible to analyze for the value of  $y$  which appeared to approach that of  $x/2$ . The susceptibility and resistivity data of the products are given in Figs. 4 and 5. It can be seen that the Néel point is no longer observable when there is greater than 2.5 atomic percent cadmium substitution for lanthanum. All samples showed p-type metallic behavior with a decrease in the resistivity as cadmium is introduced into the sample. Annealing the products in argon increases the observed Néel temperatures and also the resistivity (Fig. 6, 5). These observations are also consistent with the Goodenough model (2, 3). It therefore appears that the substitution of Bi, Pb and Cd all increase the degree of electron delocalization in  $\text{La}_2\text{CuO}_4$ , and that annealing of the samples in argon results in an increase in localization and splitting of the  $\sigma^*$  band with most of the hole concentration located in the  $\sigma^*$  upband.

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#### References

1. C-M. Niu, J. DiCarlo, K. Dwight, and A. Wold. To be published JSSC.
2. J. B. Goodenough. J. Mat. Education, **9** (6), 619 (1987).
3. J. B. Goodenough, A. Manthiram, Y. Dai, and A. Campion. Superconductor Science and Technology, IOP Publishing Co. Ltd., Bristol, England (in press).
4. D. U. Guker, R. A. Hein, S. H. Lawrence, M. S. Osofsky, D. J. Schrod, L. E. Toth, and S. A. Wolf, Phys. Rev. B, **35**, 5350 (1987).
5. R. Ward and J. D. Struthers, J. Amer. Chem. Soc., **59**, 1849 (1937).

TABLE 1

PROPERTIES OF  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  As Prepared at 950°C

Compound (x = )	Lattice Parameter(A)			$\delta$	$T_N$ (K)	$\rho$ (77K) ( $\Omega$ -cm)
	a	b	c			
0.00	5.357(2)	5.400(2)	13.16(1)		240	1
0.002	5.355(2)	5.402(2)	13.15(1)		230	
0.01	5.358(2)	5.403(2)	13.16(1)		185	$10^{-1}$
0.02	5.353(2)	5.397(2)	13.16(1)			
0.05	5.353(2)	5.396(2)	13.16(1)	0.01		
0.10	5.351(2)	5.380(2)	13.18(1)	0.02		
0.15	5.354(2)	5.378(2)	13.20(1)	0.03		$10^{-2}$
0.2	5.355(2)	5.380(2)	13.21(1)	0.03		$10^{-2}$

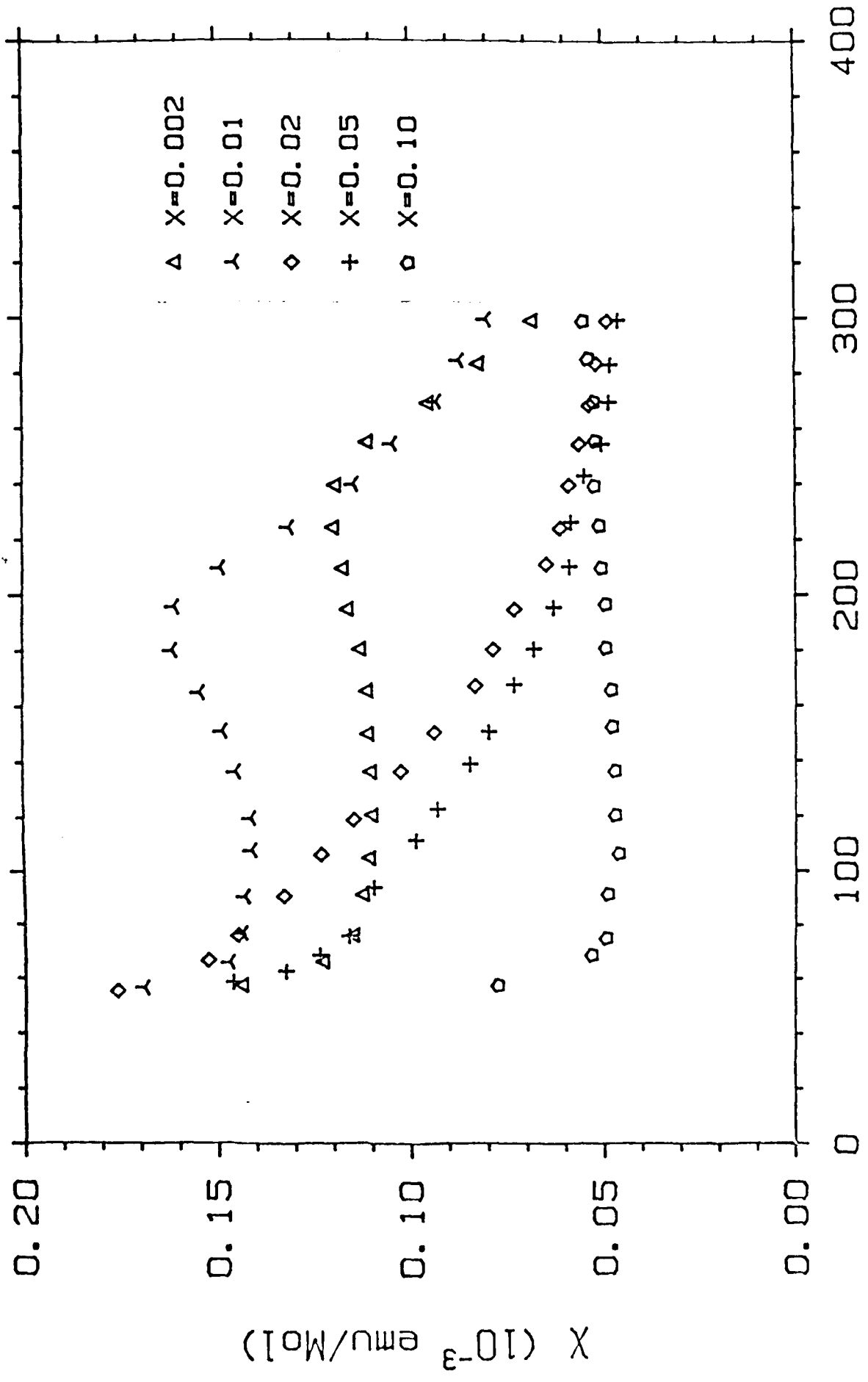
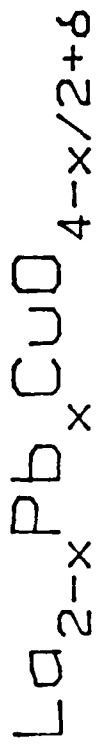
TABLE 2  
 PROPERTIES OF  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x}\text{2}+\delta$   
 ANNEALED IN ARGON AT 600°C

Compound (77K) (x = )	Lattice Parameter(Å)			$\delta$	$T_N$ (K)	$\rho$ ( $\Omega\text{-cm}$ )
	a	b	c			
0.00	5.356(2)	5.406(2)	13.15(1)		300	
0.002	5.355(2)	5.404(2)	13.14(1)		280	
0.01	5.355(2)	5.403(2)	13.15(1)		200	1
0.02	5.354(2)	5.399(2)	13.16(1)		105	
0.05	5.357(2)	5.400(2)	13.16(1)		90	
0.10	5.352(2)	5.382(2)	13.19(1)	0.02		
0.15	5.355(2)	5.379(2)	13.20(1)	0.02		$10^{-2}$
0.20	5.354(2)	5.377(2)	13.20(1)	0.03		$10^{-2}$

## FIGURE CAPTIONS

- Fig. 1. Magnetic susceptibility as a function of temperature for members of the system  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  as prepared in air.
- Fig. 2. Temperature dependence of the resistivity of members of the system  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$ .
- Fig. 3. Magnetic susceptibility as a function of temperature for members of the system  $\text{La}_{2-x}\text{Pb}_x\text{CuO}_{4-x/2+\delta}$  annealed in argon.
- Fig. 4. Magnetic susceptibility as a function of temperature for members  $\text{La}_{2-x}\text{Cd}_x\text{CuO}_{4-x/2}$  as prepared in air.
- Fig. 5. Temperature dependence of the resistivity of members of the system  $\text{La}_{2-x}\text{Cd}_x\text{CuO}_{4-x/2}$ .
- Fig. 6. Magnetic susceptibility as a function of temperatures for members of the system  $\text{La}_{2-x}\text{Cd}_x\text{CuO}_{4-x/2}$  as annealed in argon.





Temperature (K)

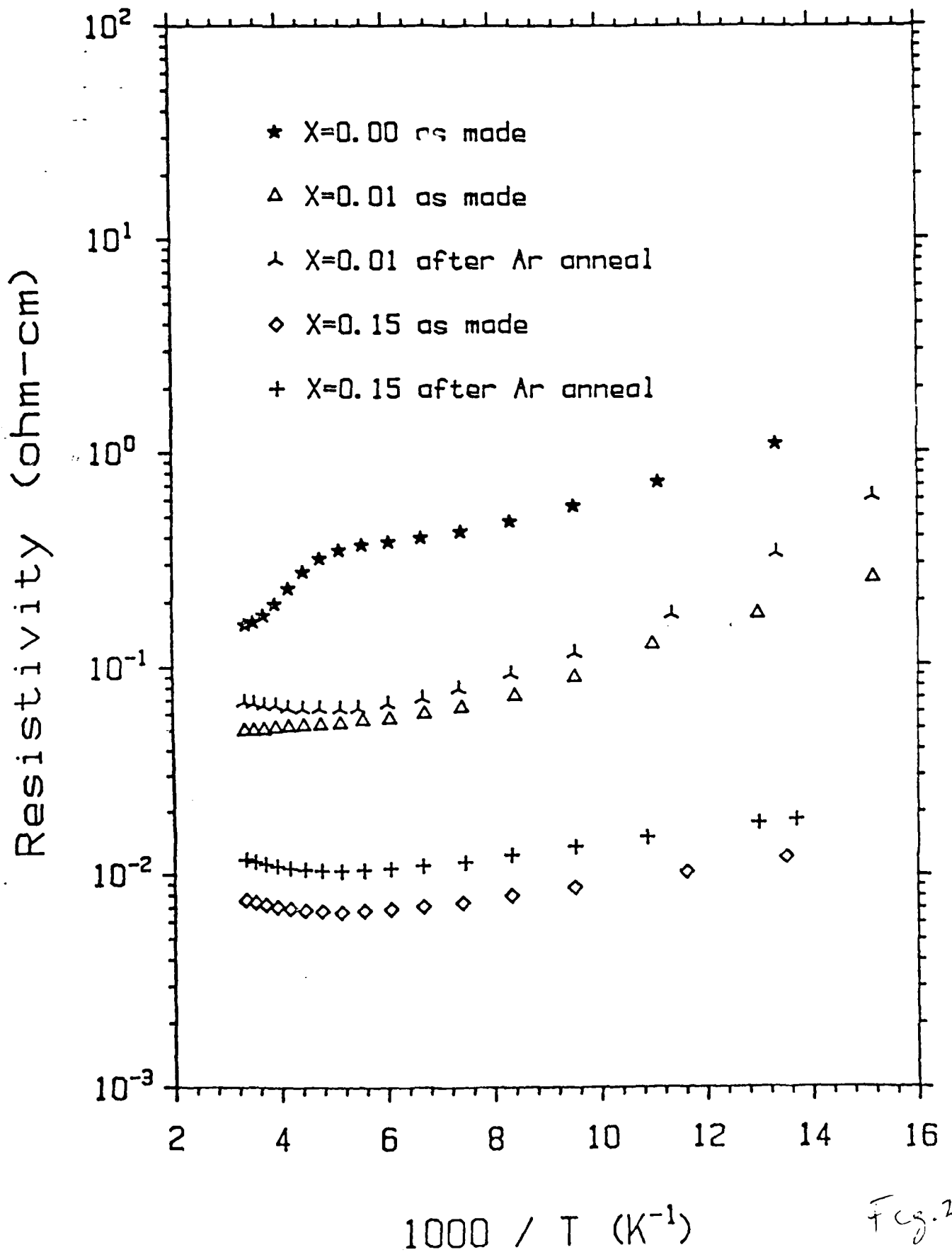
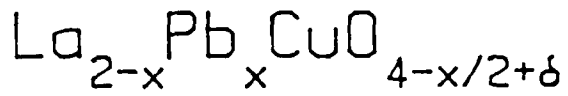
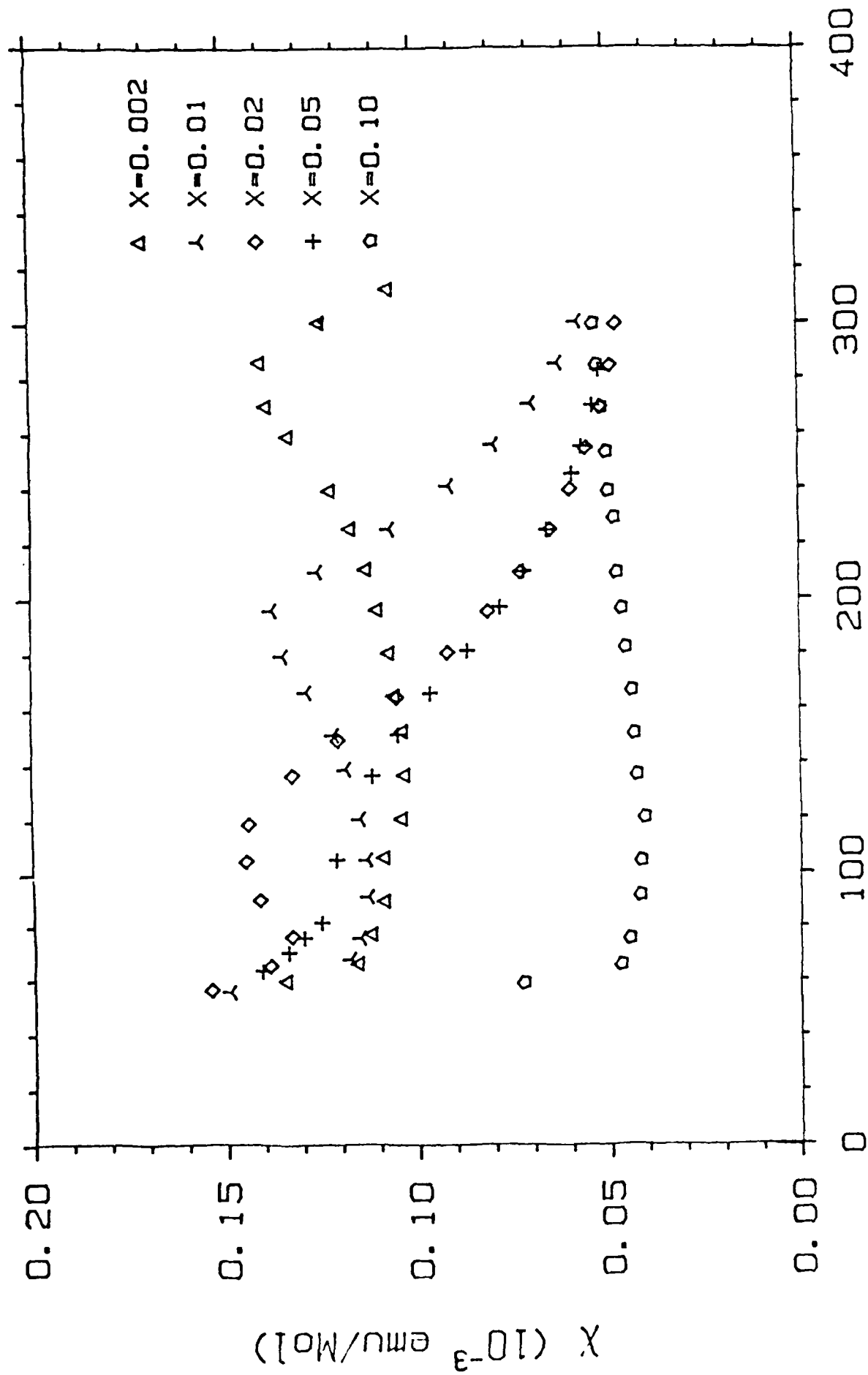
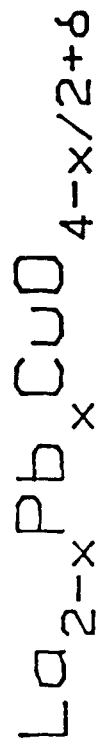


Fig. 2



Temperature (K) Fig. 3

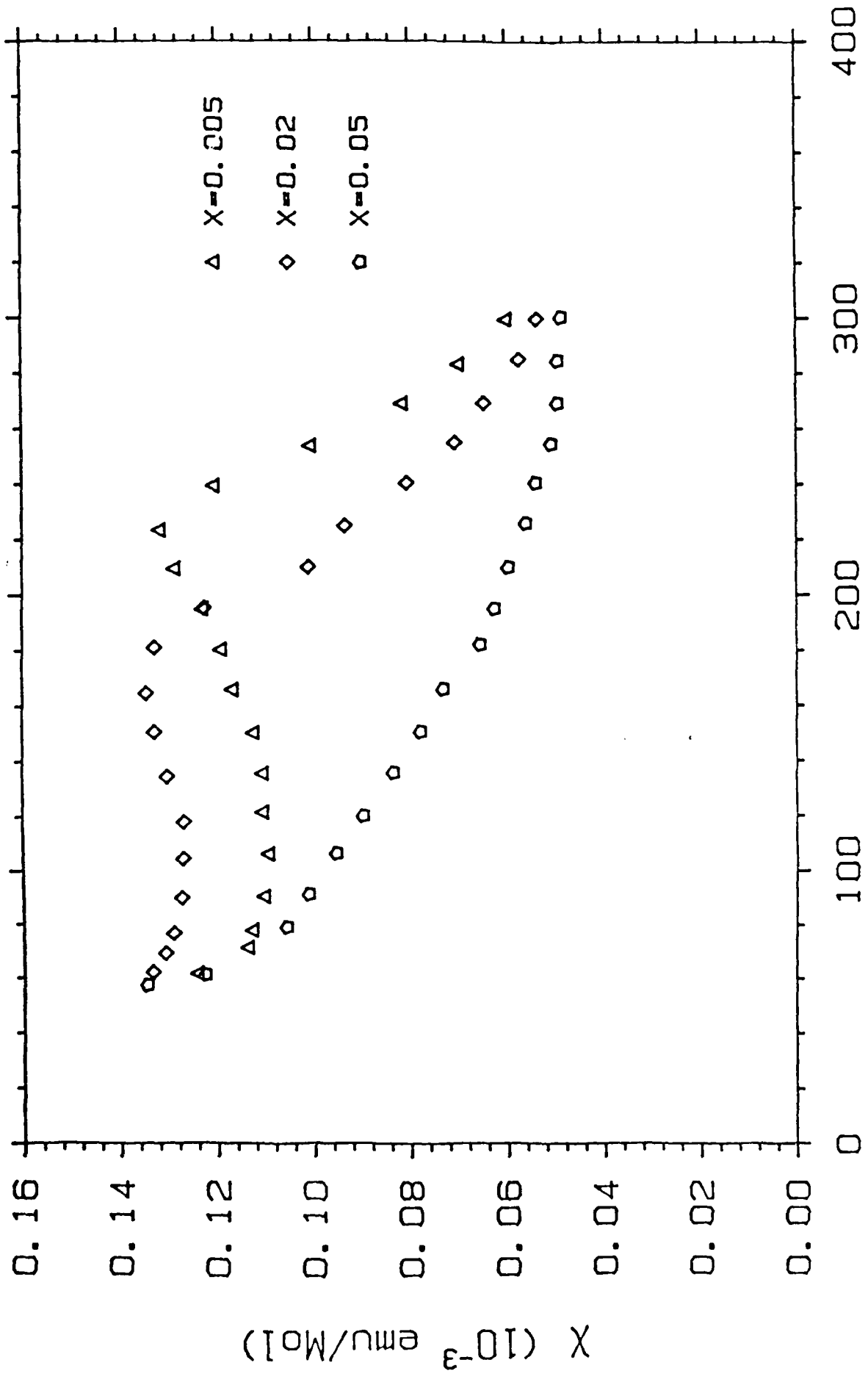
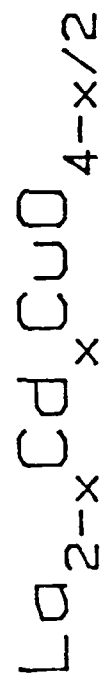


Fig. 4  
Temperature (K)

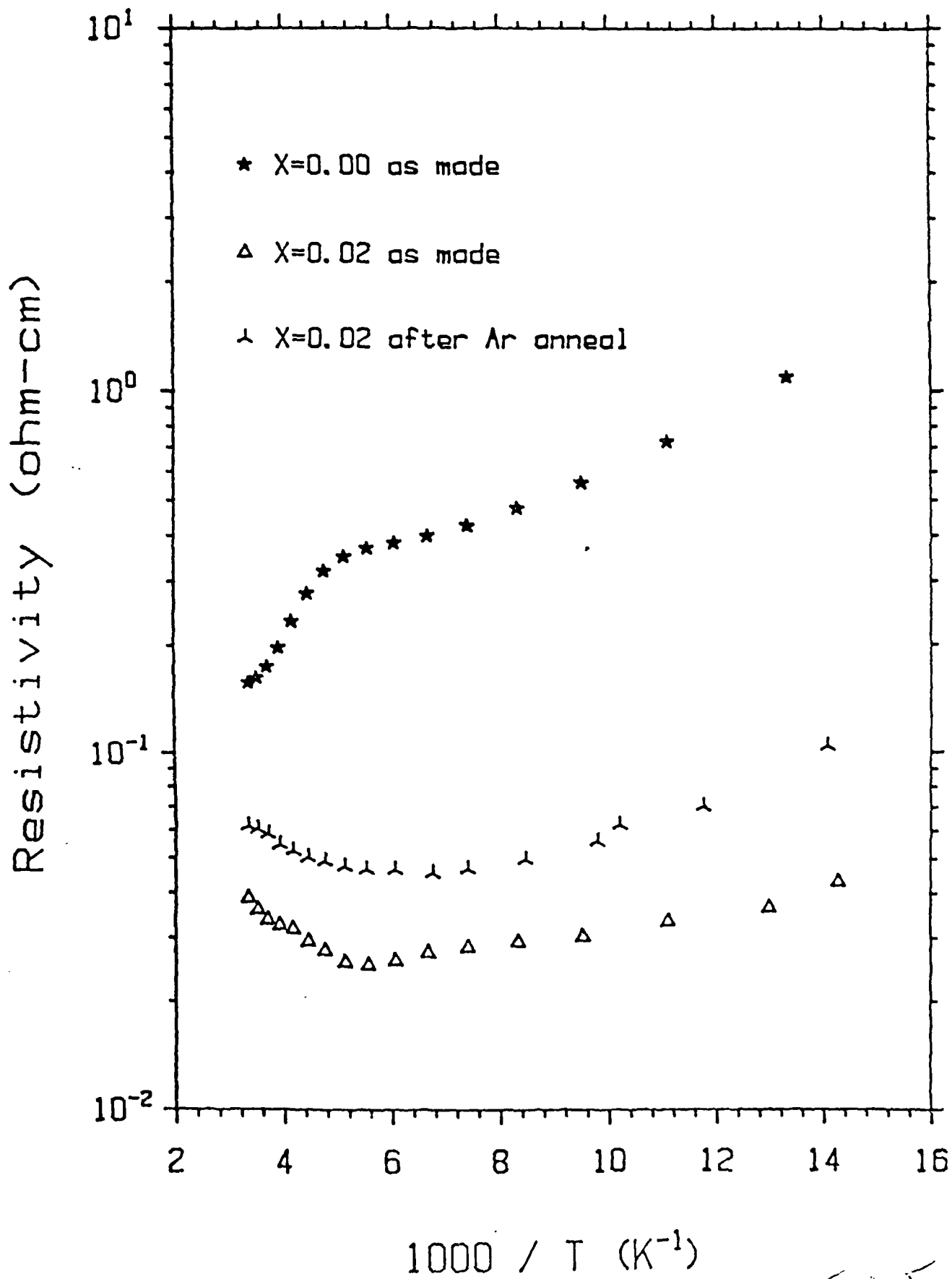


Fig. 5

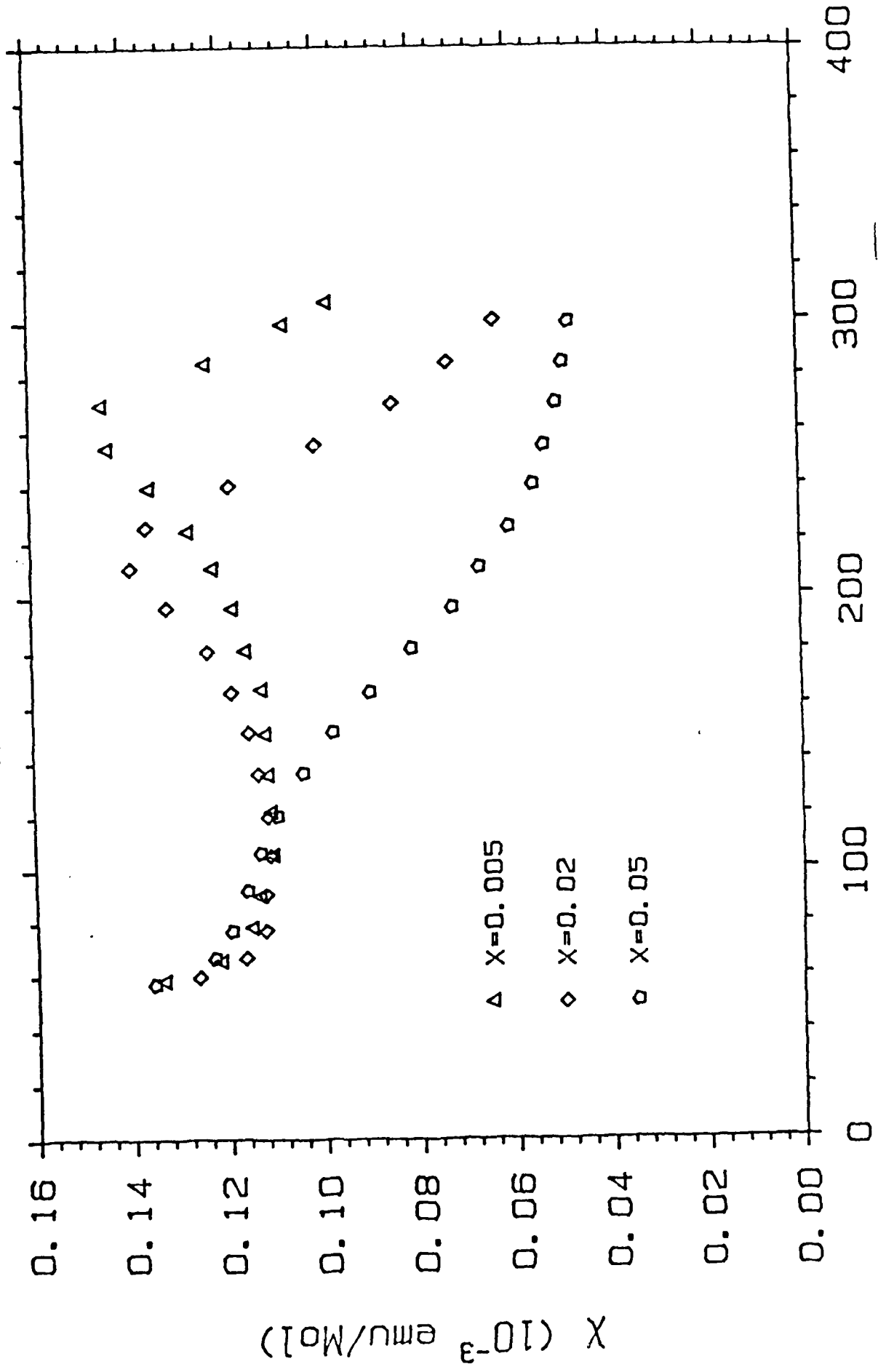
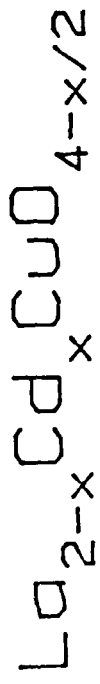


Fig. 6

Temperature (K)