Thermoelectric power factor of Ag doped YBCO samples

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ABSTRACT

Polycrystalline $YBa_2Cu_{3-x}Ag_xO_{7-\delta}$ (YBCO) samples, ($0 < x \leq 10\%$) were syntherized from oxides by solid state reaction method. The samples were submitted to a thermal process at 600^0C for one hour in order to modify their oxygen content. Seebeck coefficient S(T), electrical resistivity $\rho(T)$ of these YBCO compounds were measured in the temperature range between 77K and 300K. The electrical resistivity increases with the doping level from 10 $m\Omega cm$ to 60 $m\Omega cm$. At room temperature, the Seebeck coefficient changes from 40 $\mu V/K$ to 120 $\mu V/K$ as the Ag content is increasing. From $S(T)$ and $\rho(T)$ data the thermoelectric power factor, PF was calculated and it exhibits an enhancement with the Ag doping up to reach values about 16 $\mu W/K^2cm$.

Keywords: Power factor, Seebeck coefficient, Thermoelectric material.

RESUMEN

Mediante reacción de estado sólido se prepararon muestras policristalinas de $YBa_2Cu_{3-x}Ag_xO_{7-\delta}$ (YBCO), ($0 < x \leq 10\%$). Las muestras se sometieron a un proceso térmico a 600^0C durante una hora a fin de modificar su contenido de oxígeno. El coeficiente Seebeck $S(T)$ y la resistividad eléctrica $\rho(T)$ se midieron en el rango de temperaturas entre 77K y 300K. La resistividad eléctrica se incrementa con el nivel de dopado desde 10 $m\Omega cm$ hasta 60 $m\Omega cm$. A temperatura ambiente el coeficiente Seebeck cambia desde 40 $\mu V/K$ hasta 120 $\mu V/K$ con el incremento del contenido de plata. A partir de las medidas de S(T) y $\rho(T)$ se calculó el factor de potencia termoeléctrico, PF, éste muestra un incremento con el contenido de plata alcanzando valores máximos cercanos a 16 $\mu W/K^2cm$.

Palabras claves: Factor de potencia, Coeficiente Seebeck, Material termoeléctrico.

1 Introducción

The need of finding efficient thermoelectric (TE) materials that work at room temperature and below it has done that the research on this kind of materials goes away of conventional thermoelectric semiconductors[1].

The performance of a thermoelectric device depends on its dimensionless figure of merit ZT, which is given by the expression [2, 3]:

$$ZT = \frac{S^2T}{\kappa\rho} \tag{1}$$

where S is the Seebeck coefficient, ρ the electrical resistivity, κ the thermal conductivity and T the absolute temperature.

The goal of the research of thermoelectric materials is to find materials with high ZT values. In this sense there are studies focused on the reduction of the thermal conductivity and other to increase the thermoelectric power factor, PF which is defined as:

$$PF = \frac{S^2}{\rho} \tag{2}$$

where S and ρ are respectively the Seebeck coefficient and the electrical resistivity. This parameter is important because it determines the electrical properties of a thermoelectric material.

Below room temperature the best thermoelectric material are monocrystalline Bi-Sb alloys. However, there have been some works focused on using superconducting materials as passive thermoelements[4, 5]. Nevertheless, this kind of devices have had practical problems due mainly to the critical temperature of these superconducting materials, their critical current density values and their chemical stability.

Transport properties of YBCO compounds depend on both the chemical composition and the oxygen content. As a consequence of it, partial substitutions of Cu atoms by metallic elements (Ag, Au, Zn, etc.) on this system have been an important tool for the research of fundamental properties of this kind of perovskite compounds.

According to these transport properties YBCO compounds could be considered as a possible candidate to be used as termoelectric material in their normal state, beyond of their superconducting properties.

In this work, we report a study of the behavior of the thermoelectric power factor in the normal state of YBCO samples whose electrical properties were modified by means a silver doping and a thermal annealing.

2 Experimental

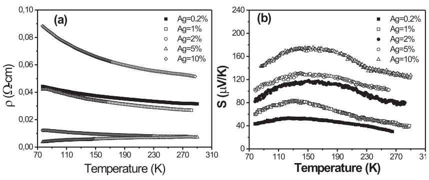

Figure 1: Temperature dependence of electrical resistivity, (a) and Seebeck coefficient, (b) of Ag-YBCO samples for different levels of silver-doping.

Samples with nominal composition $YBa_2Cu_{3-x}Ag_xO_{7-\delta}$, ($0 < x \leq 10\%$) were prepared by solid state reaction method. The superconducting samples were submitted to an annealing process at 600^0C in vacuum ($10^{-3}mb$) for one hour in order to modify both their oxygen content and their ordering.

Seebeck coefficient data was obtained by using the differential technique, in which the temperature difference generated across the sample was detected by a copper-constantan-copper thermocouple and the respective thermo-voltage was measured by copper wires attached to the sample by silver conductive paint. The accuracy of $S(T)$ data was $0.1\mu V/K$.

On the other hand, the electrical resistivity was measured by the standard four probe method, with an accuracy of $0.01m\Omega cm$. $S(T)$ and $\rho(T)$ measurements were carried out in the temperature range between 77K and 300K. Additionally, the structural properties of the samples were studied by powder x-ray diffraction analysis.

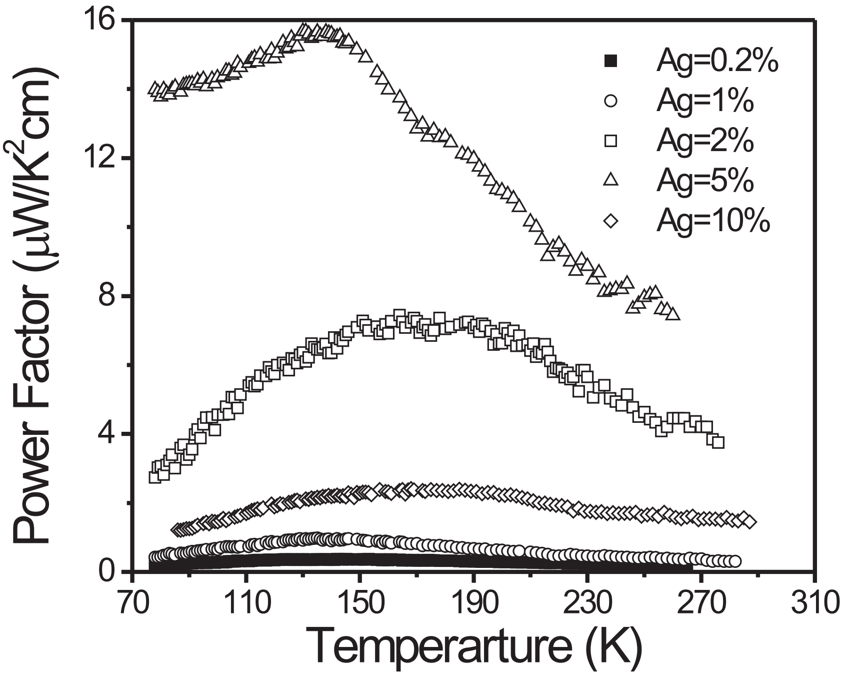

Figure 2: Temperature dependence of thermoelectric power factor $PF = S^2/\rho$ of Ag-YBCO samples for different levels of silver content.

3 Results and Discussion

The x-ray diffraction analysis showed that the samples without post-annealing treatment were superconducting YBCO-123 single phase. The structural properties of annealed samples exhibit the typical behavior of low oxygenated YBCO samples.

The electrical resistivity at room temperature (see figure 1a) is about 3 $m\Omega cm$ for undoped samples and it increases with Ag content up to reach 60 $m\Omega cm$ for high doped samples (Ag=10%). The behavior of $\rho(T)$ in the normal state changes from metallic to semiconducting as the Ag content is increasing. It is important to notice that for low doping level samples the electrical properties improve with the Ag content (see figure 1a), which is a typical behavior of these Ag doped YBCO compounds[6, 7, 8, 9]. However, the superconducting transition about $90K$ is not observed in the samples.

The Seebeck coefficient, S(T) is positive in whole measured temperature range and its magnitude increases with the Ag doping level (see figure 1b). This behavior suggests that the charge carrier density is being affected directly by the adding of Ag and by the thermal treatment.

By means of $S(T)$ and $\rho(T)$ data, the thermoelectric power factor PF was calculated (see figure 2), it is about $0.1\mu W/K^2cm$ for low-doped samples and it increases up to reach values close to 16 $\mu W/K^2cm$ for the samples with $Ag = 5\%$, this values are comparable to those of conventional thermoelectric materials. It is important to notice that the sample with $Ag = 10\%$ has the highest Seebeck coefficient values but its electrical resistivity is the highest too, as a consequence of it its PF is not the best.

These results are an indication that these YBCO materials could be a promissory thermoelectric material if they are submitted to proper changes in both their chemical composition and their oxygen content.

4 Conclusions

The behavior of electrical resistivity and Seebeck coefficient indicates that the charge carrier density is directly affected by thermal process and the Ag doping. Despite the power factor values are smaller than those of conventional semiconductors, these results show that the doping and thermal processes can improve the thermoelectric properties of YBCO compounds and become them in a promissory thermoelectric material.

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