Physica C 505 (2014) 100–103

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Variable range hopping conduction and superconductivity in Ru-1222

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ARTICLE INFO

Article history:
Received 15 July 2014
Accepted 24 July 2014
Available online 4 August 2014

Keywords:
Ruthenocuprate
Synthesis
Superconductivity
Variable range hopping

ABSTRACT

$RuSr_2Gd_{1.4}Ce_{0.6}Cu_2O_y$ (Ru-1222) with several oxygen content y has been synthesized and studied. The normal state may be of different nature including the hopping conduction. Even though the nature of the normal state conduction varies widely, superconducting state is observed over a wider range of oxygen content. A critical oxygen content $y = 10.5$ is found for which three dimensional variable range hopping conduction (3DVRH) in Ru-1222 is observed in the entire range of temperature. Clearly the origin of the superconducting transition in Ru-1222 may be governed by factors other than the carrier concentration.

1. Introduction

The transition temperature and the nature of the transition in ruthenocuprate superconductor vary widely depending on the carrier concentration, magnetic ordering and disorder level [1–9]. In polycrystalline ruthenocuprate the dependence of the transition temperature and the width of transition on carrier concentration are even more complex because of the presence of the intergranular networks. It is important to know how the oxygen content in bulk ruthenocuprate affects transition temperature and its width. In bulk $RuSr_2Gd_{2-x}Ce_xCu_2O_y$ (Ru-1222) the superconducting properties can be tuned in several ways. Among these methodologies, the change in the normal state and superconducting transition is studied by using several oxygen concentrations. As a result of varying the oxygen content the impact may include change in granular nature, carrier concentration, disorder level and magnetic ordering. To our knowledge there is no report in which the impact of the oxygen content in Ru-1222 with Ce concentration of $x = 0.6$ has been studied. Therefore, we have systematically studied bulk Ru-1222 to focus on possible impacts of the oxygen content induced parameters.

We have synthesized $RuSr_2Gd_{1.4}Ce_{0.6}Cu_2O_y$ (Ru-1222) by using oxygen content $y = 9.0$, 9.5, 10.0, 10.5 and 11.0. Samples are characterized by using X-ray diffraction (XRD) method. Morphology studies are carried out by using Scanning Electron Microscope (SEM). We have studied the impact of the oxygen content on the normal state and superconducting transition in (Ru-1222). For the first time we have studied in Ru-1222 that even though variable range hopping conduction is observed for limited oxygen content, superconducting properties are observed over a wide range of the same.

2. Experimental

We have synthesized $Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_y$ or Ru-1222 compounds following the usual solid state reaction method. Samples with oxygen content $y = 9.0$, 9.5, 10.0, 10.5 and 11.0 have been synthesized and characterized. Typically a mixture of RuO_2, SrO, Gd_2O_3, CeO_2 and CuO have been used. Using (a) calcinations at 900 °C for 24 h and (b) sintering at 1070 °C for 72 h in flowing oxygen samples have been synthesized. Samples are characterized by using the X-ray diffraction (XRD) and Scanning electron microscopy (SEM). The transport measurements have been done with the help of a Janis closed cycle cryogenerator (10–300 K). The resistivity as a function of temperature has been measured by using the standard four-probe technique [10,11].

3. Results and discussions

We have carried out XRD measurements in all samples with different oxygen content y. In Fig. 1 the intensity versus 2θ plots are shown. We have labeled all major peaks associated with Ru-1222 phase. The lattice constants of all samples are estimated using the positions of major peaks and are listed in Table 1. All samples are found to be in the single phase. In addition, the lattice constants are comparable to that of Ru-1222 prepared by other routes [12]. With the change in the oxygen content the peak position and shape corresponding to (*110*) reflections remains almost unchanged indicating that there is no major structural change in

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http://dx.doi.org/10.1016/j.physc.2014.07.014
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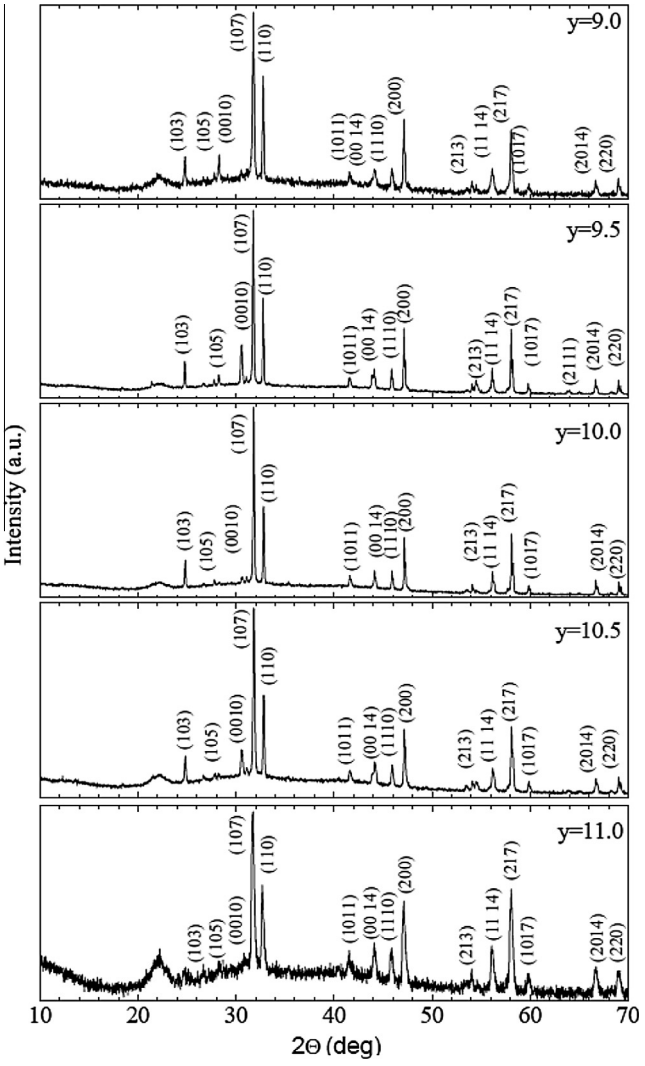

Fig. 1. X-ray diffraction (XRD) patterns of $RuSr_2Gd_{1.4}Ce_{0.6}Cu_2O_y$ with oxygen content $y = 9.0$, 9.5, 10.0, 10.5 and 11.0.

Table 1
Lattice constants of Ru-1222 with different oxygen content y.

Sample	a (Å)	c (Å)
$Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_9$	3.8555	28.8726
$Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_{9.5}$	3.8571	28.9116
$Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_{10}$	3.8525	28.8412
$Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_{10.5}$	3.8555	28.7936
$Ru_1Sr_2Gd_{1.4}Ce_{0.6}Cu_2O_{11}$	3.8571	28.9557

CuO_2 planes. Therefore, oxygen content may not affect the overall disorder level in Ru-1222.

Using the scanning electron microscope (SEM) the granularity and microstructure have been studied in Ru-1222 with different y. We have shown micrographs of Ru-1222 with different y in Fig. 2(A–E). The nature of granularity is almost similar in four samples with $y = 9.0$, 9.5, 10.0 and 11.0. However, the granularity is different in sample with $y = 10.5$. Clearly intergranular separations are almost removed. Distinct grains are visible almost in the entire panel (see Fig. 2D). Typical grains of highest dimension of 4–5 μ are clearly dominating in $y = 10.5$. The grain size of Ru-1222 with $y = 10.5$ is comparable to that reported earlier [13]. However, in other samples most of the micrographs show no measureable isolated grain. The grain boundaries are not clearly distinguishable in most of the regions of the SEM images for $y = 9.0$, 9.5, 10.0 and 11.0. Therefore isolated regions are observed to form most of parts in samples.

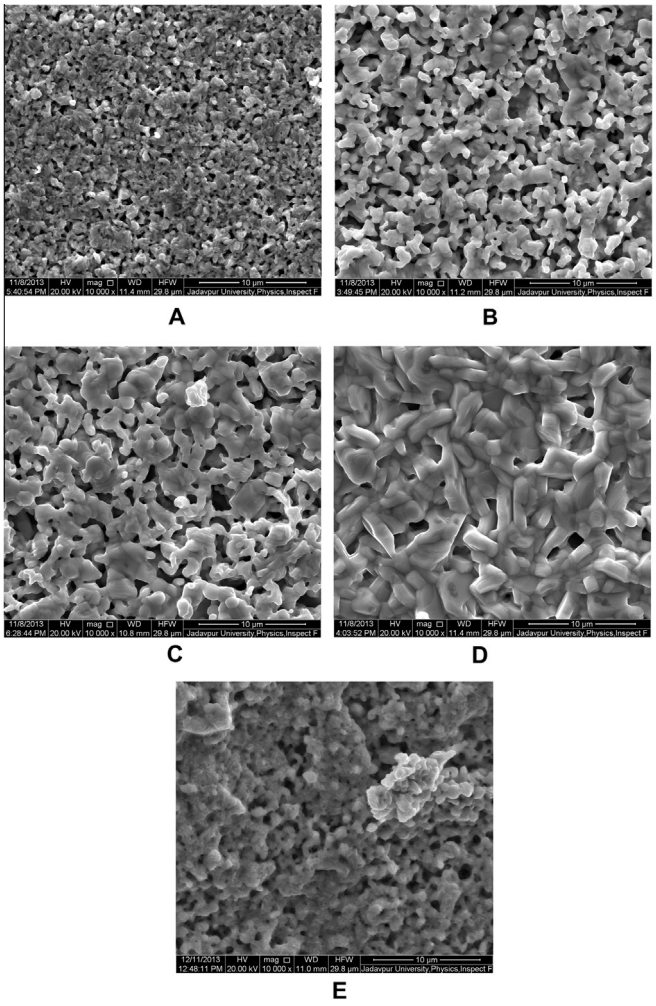

Fig. 2. Scanning electron micrographs (SEM) of Ru-1222 samples with $y = 9.0$ (A), 9.5 (B), 10.0 (C), 10.5 (D), and 11.0 (E).

The resistivity as a function of temperature has been plotted in Fig. 3. In the inset of Fig. 4 we have plotted T_c as a function the oxy-

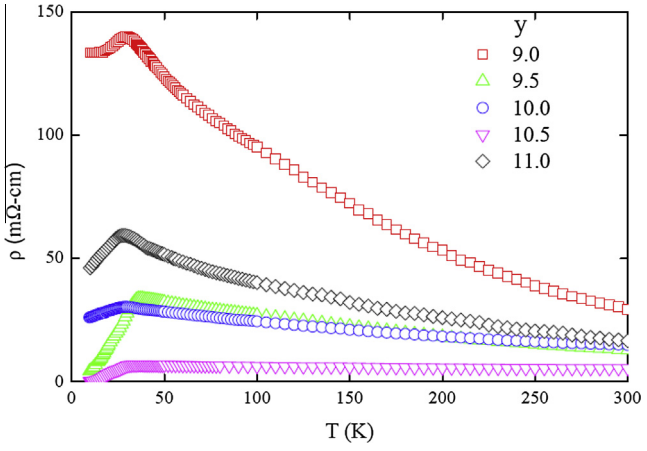

Fig. 3. Resistivity as a function of temperature of $RuSr_2Gd_{1.4}Ce_{0.6}Cu_2O_y$ with oxygen content $y = 9.0$, 9.5, 10.0, 10.5 and 11.0.