Scanning Tunneling Microscopy Studies of High Jc NEG123 Crystals

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Abstract

We have performed ultrahigh vacuum (UHV) scanning tunneling microscopy (STM) measurements at room temperature on NEG123 ($(Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba_2Cu_3O_y$) crystals grown by an oxygen controlled melt growth (OCMG) process. Two characteristic nano structures, namely, modulation and island structures have been observed on a cleaved surface of the NEG123 with high J_c and high irreversible field H_{irr} higher than 10 T at 77 K. These structures may be associated with an element substitution and the good J_c-B property.

Key words: Scanning Tunneling Microscopy; High-Tc superconductor; Substitution effect; Modulation structure

1. Introduction

$REBa_2Cu_3O_y$(RE = Nd, Eu, Gd, Y) superconductors have a significant potential for high field power applications due to high J_c and high irreversible field H_{irr}. Recent experiments have proved that $(Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba_2Cu_3O_y$ (NEG123) superconductors exhibit superior electromagnetic properties among the RE123 compounds [1, 2].

NEG123 is well-known to show a peak effect in the magnetization curve. This effect implies the presence of strong pinning centers of weak superconducting character. It is important, therefore, to elucidate the detailed structures responsible for the pinning centers.

In this paper, we report the experimental results on the cleaved surfaces of two different NEG123 crystals obtained by an ultrahigh vacuum (UHV) scanning tunneling microscopy (STM). We observed two characteristic nano structures. One is a nm-size island structure on a cleaved surface of NEG123 with 40 mole% of NEG211, the other is a modulation structure on a cleaved surface of NEG123 with 5 mole% of NEG211 with high J_c and high H_{irr} higher than 10 T at 77 K.

These structures may be associated with an element substitution and the good J_c-B property.

2. Experimental

NEG123 crystals were grown by an oxygen controlled melt growth (OCMG) process, under 0.1 % O_2 and a gas flow rate of 300 ml/min. The chemical compositions of sample A and sample B were NEG123 ($(Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba_2Cu_3O_y$) with 5 mole% of (Nd, Eu, Gd)211 and with 40 mole% of (Nd, Eu, Gd)211, respectively. The details of the growth conditions are given elsewhere [3]. Samples exhibited the superconducting transition temperature T_c of 93 K as determined by SQUID measurements.

All STM observations were made at room temperature in ultrahigh vacuum (UHV) using an STM system (JSTM-4000XV). The STM tip (Pt-Ir) was cleaned by electron bombardments prior to observation.

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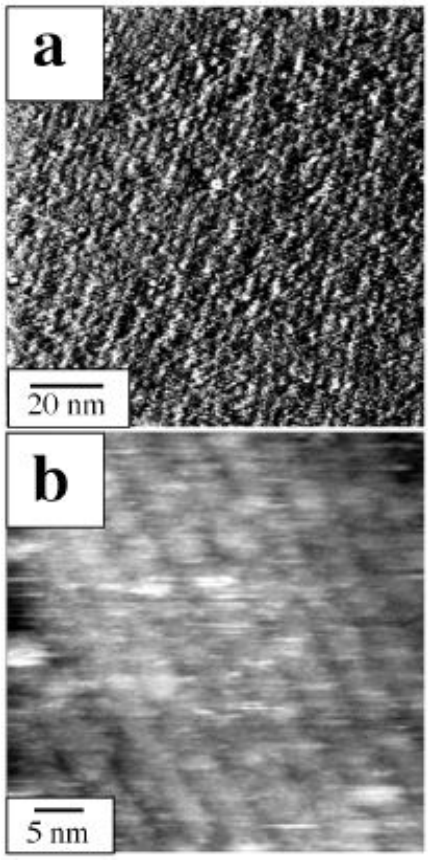

Fig. 1. STM image on the cleaved surface of NEG123 with 5 % NEG211. The tunneling conditions are Vs = 1.0V, It = 0.3 nA. The image sizes are (a) 100 x 100 nm^2 and (b) 38 x 38 nm^2, respectively.

3. Results and discussion

Figure 1 shows an STM image of NEG123 crystal with 5 % NEG211 (sample A) taken with a sample bias voltage, Vs of 1.0V. These images in Fig.1(a) and (b) were taken in a constant height mode and in a constant current mode, respectively. As can be seen, there are modulation structures with about 4 nm periodic arrangement. The height of modulation is 0.5 nm.

Although, it is hard to note a nm size island structure in Fig.1(b) because the structure is more disturbed and has a weak contrast. Careful examination of the images shown in Fig.1(b) tells us that the island structure is along the modulation.

Figure 2 shows an STM image of NEG123 crystal with 40 % NEG211 (sample B) taken in a constant current mode. The image in Fig.2, which is different from that in Fig.1, clearly shows a few nm size island structures, but no modulation structures. These experimental results indicate that an amount of NEG211 phase in NEG123 affect the structure of matrix (NEG123).

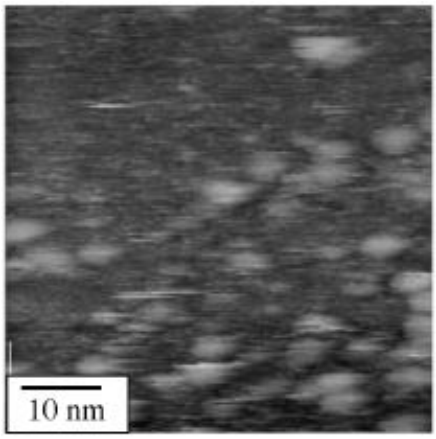

Fig. 2. STM image on the cleaved surface of NEG123 with 40 % NEG211. The tunneling conditions are Vs = 1.0V , It = 0.3 nA and the image size is 50 x 50 nm^2.

Similar island and modulation structures where the Ba^{2+} site of Nd123 is partially occupied by Nd^{3+} ions, have been reported in Nd123 single crystals [4, 5], but for the first time for NEG123 crystals by STM. For Nd123, the size of the island is much bigger (a couple of tens of nanometers). However, the present STM results are also consistent with TEM and AFM results by our data. It is interesting that the size of islands in Fig.1(b) is the same scale as that in Fig.2.

We have succeeded in observing modulation structures with a width of about 4nm and a few nm size island structure on the NEG123 cleaved surface. These structures may be associated with an element substitution and the good J_c-B property. To confirm this, further STM/STS mesurements at low temperatures are required.

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