The fabrication of MgB_2 superconducting STM tips

Mingxiang Xu [1], Yoshihiko Takano, Takeshi Hatano, Masayo Kitahara, Daisuke Fujita

National Institute for Materials Science, 1-2-1, Sengen, Tsukuba 305-0047, Japan

Abstract

We demonstrate a simple method for the fabrication of reproducible, clean and stable MgB_2 superconducting tips. The quality of these tips has been verified by imaging the surface of a thin Au(111) film sample using a low temperature scanning tunneling microscopy (STM). High-quality semi-atomically resolved STM surface images of the Au(111) sample have been observed using the MgB_2 superconducting tip, which unambiguously indicates that the fabrication of relatively superconducting MgB_2, suitable for use as STM tips, is feasible.

Key words: MgB_2; scanning tunneling microscopy (STM); Au(111) surface

1. Introduction

The scanning tunneling microscopy (STM) has provided unique insights into the local density of electronic states (LDOS) of metal, semiconductor and superconductor surfaces [1–3]. STM studies of superconducting materials are conventionally performed in the superconductor/insulator/normal-metal (S/I/N) configuration using a sharp normal-metal tip. A natural and intriguing extension of the capabilities of STM studies would be to use a superconducting tip, thus allowing for S/I/S measurements. The use of superconducting tips for tunneling experiments into high-T_c superconductors has been predicted by theoretical calculations [4,5]. Quasiparticle tunneling from a superconducting atomically sharp Nb tip has been verified to be indeed feasible [6]. The idea of STM experiments in which the Josephson effect would be observed between the tip and the surface was also suggested [6].

Since the recent discovery of 39 K superconductivity in magnesium diboride MgB_2 [7], a variety of its high potential applications have also been discussed [8]. However, the idea of using MgB_2 as the material for the STM tip has not yet been reported in the literature. In this article, we demonstrate a simple method for the fabrication of reproducible, clean and stable MgB_2 superconducting tips. The quality of these tips has been verified by imaging the surface of a thin Au(111) film sample using a low temperature STM.

[1] Corresponding author. E-mail: xu.mingxiang@nims.go.jp

2. Fabrication and Characterization

The superconducting MgB_2 tips used in this study were made of dense polycrystalline samples. The highly dense (density ~ 2.63 g/cm^3) MgB_2 bulk samples were synthesized under high pressure (3.5 GPa) at high temperature (1273 K) for 2 h in a BN crucible as described elsewhere [9]. X-ray diffraction reveals that the sample is single phase. Magnetization measurements show a superconducting transition with an onset and a midpoint at 38.3 and 37.8 K, respectively. A small (about 2 mm in length) piece was first cleaved from the MgB_2 sample and glued with silver paint on a STM tip holder, then immediately loaded in an ultrahigh vacuum (UHV) STM chamber. The surface was finally cleaned with Ar ion sputtering (1 keV) in UHV. Using such a simple method, we have thus obtained clean MgB2 superconducting tips with a high degree of reproducibility. The thin Au(111) film sample was made by vapor deposition of pure gold on a single-crystal mica substrate at 500 K in vacuum. The surface was

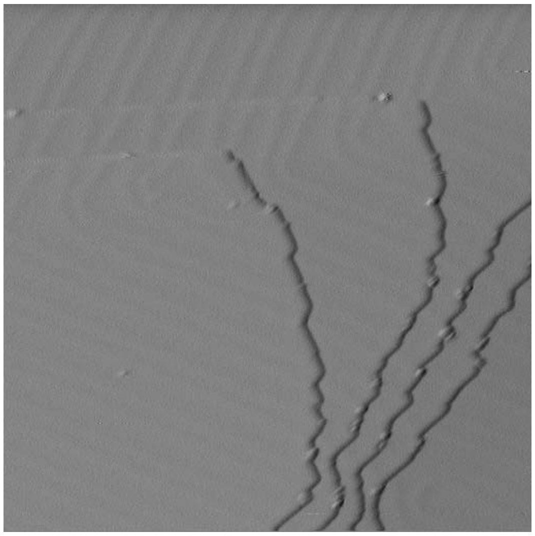

Fig. 1. A wide-area STM image (104 × 104 nm^2) at the constant-height mode (V_T = -2.00 V, I_T = 0.20 nA) of the reconstructed Au(111) surface observed at 30 K, clearly showing the steps of monoatomic height and the herringbone patterns.

cleaned with Ar ion sputtering at the acceleration energy of 1 keV, followed by annealing at 500 K in UHV. By this method, epitaxially grown Au(111) surfaces with atomically flat terraces were routinely obtained.

In order to characterize the MgB_2 tips, we have performed surface imaging on the thin Au(111) film sample, using a low temperature STM (UNISOKU, Japan) operated in UHV with a base pressure of 3×10^{-9} Pa. STM images of the Au(111)-(23 × $\sqrt{3}$) reconstructed surfaces were observed with semi-atomic resolution using a constant-height imaging mode.

3. Results and Analyses

Figure 1 shows a wide-area STM image (104 × 104 nm^2) at the constant-height mode (V_T = -2.00 V, I_T = 0.20 nA) of the Au(111) surface observed at 30 K. Here V_T and I_T are the sample bias and the tunneling current, respectively. Several monoatomic steps of 0.24 nm height, separating upper and lower terraces, were clearly observed. Moreover, this image of the Au(111) surface also clearly shows the existence of herringbone-like patterns on the terraces. The domain size of the herringbone pattern, defined as the distance between adjacent domain walls which separate different orientations of the (23 × $\sqrt{3}$) reconstruction, is estimated to be in the range 10 – 20 nm, which is consistent with the reported data [10]. Such a semi-atomically resolved STM image, which clearly exhibits the topographic nature of the reconstructed Au(111) surface, unambiguously confirms that the MgB_2 superconducting tip is stable and practicable.

4. Conclusions

In conclusion, we have demonstrated a method for the fabrication of clean and stable MgB_2 superconducting tips. Herringbone reconstruction of Au(111) surface was clearly resolved by the MgB_2 tip using a low temperature STM. A semi-atomically resolved STM surface image of a Au(111) sample was observed, which unambiguously confirms that the cleaved MgB_2 tip has the capability of high atomic resolution.

Our superconducting-tip STM can, hence, open the door for many important future applications. Most notable example is Josephson tunneling in SS-STM, which would provide a new type of tunable Josephson junction. It could also become a useful instrument to study, for example, spatial variations of the order parameter in exotic superconductors. Using the MgB_2 superconducting tip, further STM studies on MgB2 superconductor are now in progress.

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