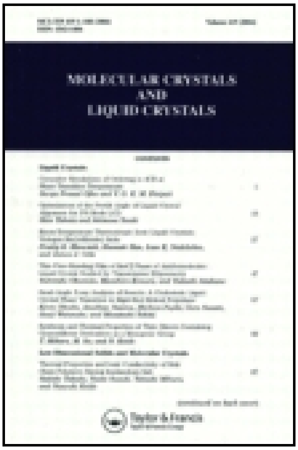

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

STM Studies of NaCl Thin Films on Cu(111) Surface at Low Temperature

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Version of record first published: 22 Sep 2010

Mol. Cryst. Liq. Cryst., Vol. 472, pp. 321/[711]–325/[715], 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701548605

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NaCl thin films on Cu(111) surfaces have been studied by scanning tunneling microscopy at 78 K. Standing wave patterns appeared not only on the Cu(111) but also on the NaCl films. The wave vector of the standing waves on the NaCl films was shorter than that on the Cu(111), indicating that the energy dispersion of the interface states on the NaCl films shifted upward from that of the Cu(111).

Keywords: low temperature scanning tunneling microscopy; standing wave patterns; surface states

INTRODUCTION

It is well known that electrons occupying surface states on noble metals form a nearly free electron gas (NFEG) in two dimension and exhibit a parabolic energy dispersion [1–3]. Steps and adsorbates on noble metal surfaces act as scattering centers of electrons of surface states to generate electron standing wave patterns (ESWPs) [4–8]. Suzuki *et al*. have observed ESWPs on Pd adlayers on Cu(111) and Au(111) surfaces by low-temperature scanning tunneling microscopy (STM) at 4.2 K [8]. Based on the analysis of ESWPs, they found that Pd adlayers modified the ESWPs and the energy dispersion of the

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surface states on Pd shifted upward from that of the bare noble metal surfaces due to the reduction of the electron density. Thus the detail analysis of ESWPs gives the information of the interface between adsorbates and metal surfaces.

It is interesting to study the effect of insulator films which have a wide band gap and make less contribution to the electronic states around the surface states. Park *et al*. have studied the effect of Xe adlayers on Cu(111) surfaces [9]. They found that Xe adlayers modified ESWPs and the energy dispersion on Xe adlayers shifted upward from that on the bare Cu(111) surfaces. In the present work, we deposited thin NaCl films on Cu(111) surfaces and investigated their effects onto ESWPs on the surface by STM at 78 K.

EXPERIMENTAL

Experiments were performed in a low-temperature scanning tunneling microscope consisting of three differently-pumped chambers; load-lock, preparation and observation chamber. A Cu(111) film was grown epitaxially on a cleaved mica. The Cu(111) surface was cleaned by repeated cycles of Ar^+ sputtering and annealing at 700 K in the preparation chamber. Atomic resolution of the Cu(111) and ESWPs were observed by STM. NaCl was evaporated from Knudsen cell onto the Cu(111) surface at room temperature. After the evaporation, the sample was transferred into the observation chamber and imaged at 78 K. A Pt/Ir wire was used as a tip. Differential conductance (dI/dV) images were acquired simultaneously with STM image by lock-in detection.

RESULTS AND DISCUSSION

Figure 1 shows an STM image of the ultrathin NaCl films on the Cu(111) observed at 78 K. The dashed line indicates the monatomic-height step of the Cu(111). The regions marked as (i) and (ii) correspond to the first and second layers of the NaCl films on the Cu(111), respectively. Figure 2(a) shows an STM image of the first layer of the NaCl film on the Cu(111) surface. The dashed and broken lines correspond to the step edges of the Cu(111) and the NaCl film, respectively. Figure 2(b) shows a dI/dV image taken simultaneously with the STM image of Figure 2(a). In Figure 2(b), the ESWP of the surface state appeared near the step edge on the Cu(111). ESWP also appeared on the NaCl layer, indicating that NFEG in two dimension was formed on NaCl films.

Figures 2(c) and 2(d) show the profiles along the line A–B on the NaCl film and the line C–D on the bare Cu surface in Figure 2(b), respectively. The wavelength of the ESWP on the NaCl film was 1.2 nm in Figure 2(c),

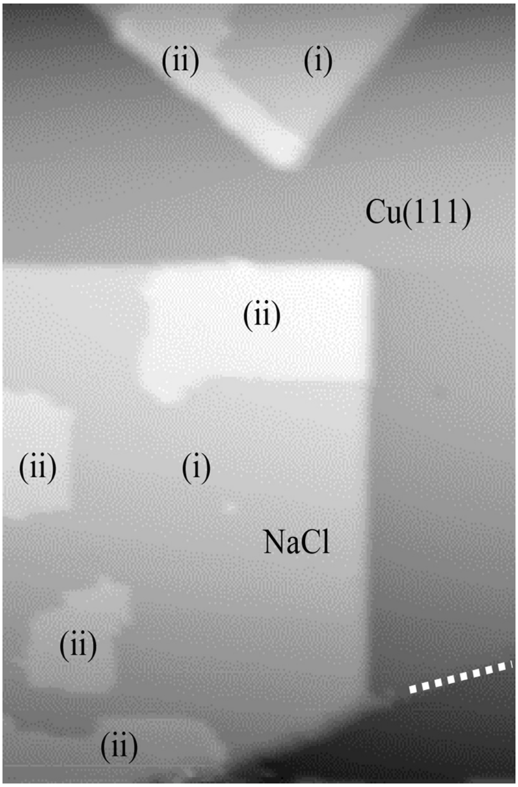

FIGURE 1 STM image of NaCl films grown on the Cu(111) surface taken at 78 K with the sample bias voltage of +2.0 V and the tunneling current of 80 pA. The scan size is 43.1 nm × 58.4 nm. The broken line indicates the position of the atomic height step of the Cu(111). The marks (i) and (ii) indicates the first and second layers of the NaCl films on the Cu(111), respectively.

while that of the ESWP on the bare Cu was 0.9 nm in Figure 2(d). The wavelength on the NaCl film was longer than that on the Cu(111). To clarify the different wavelengths of the ESWPs, Fourier transformation (FT) of Figure 2(b) was taken, as shown in Figure 2(e). Two concentric circles are visible in Figure 2(e), indicating the existence of the two ESWPs with the different wavelengths. It is well known that a FT image gives the information of the wave vectors of the surface states [10,11]. In Figure 2(e), the outer and inner circles correspond to the wave vectors of the bare Cu(111) and the NaCl film, respectively. The wave vector of the ESWP of the NaCl film is shorter than that of the bare Cu(111), which indicated that the energy dispersion of NFEG on the NaCl film shifted

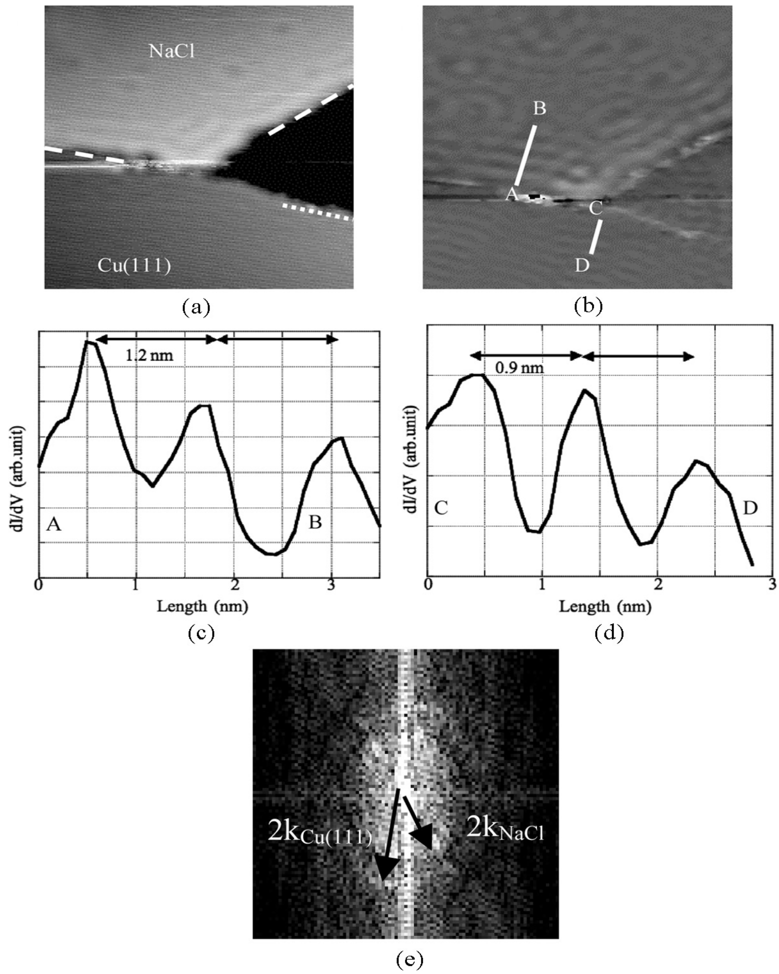

FIGURE 2 (a) STM image of a NaCl film on the Cu(111) surface taken at 78 K with the sample bias voltage of -50 mV and the tunneling current of 0.1 nA. The scan size is 19.2 nm $\times$ 24.7 nm. The dashed and broken lines indicate the step edges of the Cu(111) and NaCl film, respectively. (b) dI/dV image taken simultaneously with the STM image of Figure 2(a). (c) The profile along the line A–B in Figure 2(b). (d) The profile along the line C–D in Figure 2(b). (e) Fourier-transformed image of Figure 2(b).

upward from that of the bare Cu(111), as is the case for Xe adlayers on Cu(111) surfaces [9].

The surface states of the Cu(111) decay exponentially into the vacuum with the decay length determined by the image potential

[3,8,12,13]. Due to the interaction between the conduction band of NaCl and electrons of Cu(111), the effect of the image potential is weakened. The decay length of the surface states is, then, modified, which causes the upward shift of the energy dispersion of NFEG. Owing to the adsorption of the NaCl films, the surface states of the Cu(111) are regarded as the "interface" states localized at the interface between the Cu surface and the NaCl films. Since the interface states are located in the band gap of NaCl and the two-dimensional NFEG is formed, NaCl films are thought to metallize at the interface.

We have studied NaCl films on Cu(111) surfaces by STM at 78 K. ESWPs were observed not only on the bare Cu(111) but also on the NaCl films. The wave vector of the ESWPs on the NaCl films was shorter than that on the bare Cu(111), which indicated that the energy dispersion of the NFEG on NaCl films shifted upward compared to that on the bare Cu(111). The interface states were thought to metallize the NaCl films.

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