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STM Study of Ultra Thin Fe Films Grown on GaAs(100) Surface

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In this paper, we report on the nanometer-scale observation of the initial growth processes of ultra thin Fe films on GaAs(100) substrates using scanning tunneling microscopy(STM). The STM observation has revealed that Fe atoms are formed into many small clusters on the flat terraces of the c(4x4) reconstructed GaAs surface at room temperature(RT). The typical size of the Fe clusters is about 1.5nm which is nearly equal to the size of the unit cell of the c(4x4) reconstruction.

1. Introduction

Recently, it has been reported that Fe ultra thin films show different magnetic and electronic properties from those of bulk materials.[1-3] These properties are thought to be very sensitive to the surface structures, and closely related to the seed substrates.[4] On the other hand, the epitaxial growth of metallic thin films on semiconductor substrates is currently interesting because the crystal anisotropic and meso-scopic structures can be controlled on the substrates. So far, many experimental works have been done to clarify the growth modes and magnetic properties of magnetic ultra thin films on semiconductor substrates.[5-7] The system of magnetic metal on semiconductor is expected to be one of the new magneto-optical or magneto-resistance materials for the next generation. It has been reported that a thin Fe film grows epitaxially on GaAs(100)[8] and GaAs(110)[9] because of their small lattice mismatch. Since GaAs shows many variations of surface reconstructed structures, it is interesting to study the effect of the reconstructed surface structures of GaAs on the growth of Fe films.

In this report, the results of STM observation of the initial growth processes of ultra thin Fe films on c(4x4) reconstructed GaAs(100) substrates are presented.

2. Experimental procedures

Experiments were performed in an ultra high vacuum(UHV) multi-chamber system equipped with an STM, an Auger electron spectroscopy(AES) and a molecular beam epitaxy(MBE) system. An n-type Si-doped GaAs(100) was used as a substrate. The GaAs substrate was chemically etched by a solution of NH_4OH-H_2O_2-H_2O and loaded into the UHV multi-chamber system. After preheating, the substrate was transferred into the MBE chamber. A 10nm-thick GaAs seed layer was first grown at 560°C by MBE using Knudsen cells to obtain a clean and (2x4) reconstructed surface. The growth of the GaAs layer was controlled by monitoring the reflection-high-energy-electron-diffraction(RHEED) patterns. The (2x4) surface reconstruction changed to a c(4x4) reconstruction below about 400°C. After the growth of the GaAs seed layer, the surface was checked free from carbon and oxygen by AES.

The Fe films were evaporated onto the GaAs seed layer at RT by using an electron gun source in the STM chamber with keeping a range of 10^{-10} Torr. The nominal Fe film thickness controlled by a specially designed feed back system using a flux monitor was in the range of 0.25 to 3.2 monolayers(ML).

STM observation was carried out at RT, and the images were taken in a constant current mode with a mechanically-ground Pt-Ir tip and a tunneling current of 100pA.

3. Results and Discussion

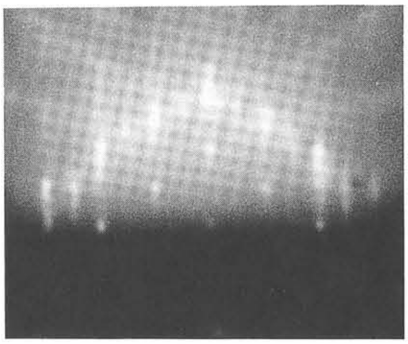
Fig. 1 shows an STM image of the GaAs surface with 0.8ML of Fe grown at RT. From this image, it is clear that Fe on c(4x4) reconstructed GaAs surface does not provide a layer by layer growth, but Fe clusters are formed on the flat terraces. The size of the Fe clusters is about 1.5nm which is nearly equal to the size of a unit cell of the c(4x4) reconstruction(1.1nm). STM images with different Fe film thicknesses from 0.4 to 0.8ML showed no appreciable changes in the density and size of the clusters.

According to the scanning tunneling spectroscopy (STS) of the film surfaces, the band gap voltage was found to be 1.45V on GaAs and 0.5V on 0.5ML Fe clusters. The band gap became smaller with increasing the Fe thickness and disappeared at 1ML. This fact shows that the electronic properties of the film surface change strongly with increasing the Fe thickness.

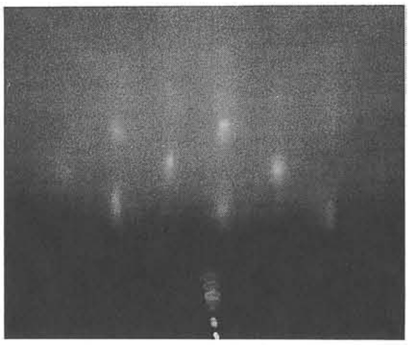
Fig. 1 100x100nm^2 STM image of 0.8ML Fe grown on the c(4x4) reconstructed GaAs(100) surface taken in a constant current mode with a 100pA tunneling current.

The RHEED pattern of the 0.4ML Fe film along the $[1\bar{1}0]$ GaAs azimuth is shown in Fig. 2(a). The RHEED pattern is subjected to a streaked one, but remains the reconstruction pattern of the GaAs(100). This fact suggests that the surface structure of GaAs is preserved after the Fe growth. The RHEED pattern of the 8ML Fe film along the $[1\bar{1}0]$ GaAs azimuth is also shown in Fig. 2(b), exhibiting the epitaxial growth of the Fe films on the c(4x4) reconstructed GaAs(100) surface. The epitaxial growth in this system is due to the fact that the lattice constant of GaAs is almost twice that of bcc-Fe.

These experimental facts suggest that the Fe clusters on the c(4x4) reconstructed GaAs(100) surface as seen in the Fig. 1 is closely related to the c(4x4) reconstruction, and the nucleation of the Fe cluster occurs at a specific position within the unit cell of the c(4x4) reconstruction of the GaAs(100) surface. The lattice matching between the Fe and GaAs may occur in the unit cell of the c(4x4) reconstruction.



(a) Fe thickness: 0.4ML



(b) Fe thickness: 8ML

Fig. 2 The RHEED patterns along the $[1\bar{1}0]$ GaAs azimuth of the 0.4ML (a) and 8ML (b) Fe grown on the c(4x4) reconstructed GaAs(100) surface.

Fig. 3 shows an STM image of 0.8ML Fe film grown at RT on a Te-stabilized (2x1) reconstructed GaAs(100) surface. Fe clusters are also observed on this surface, whose size is about 3nm on an average. It should be noticed, however, that the size is not uniform on the (2x1) reconstructed GaAs(100) surface on the contrary to the case of the c(4x4) reconstructed surface. This may be attributed to the change of the reconstruction and/or the roughness of the GaAs seed layer surface.

These experimental facts may show that the size and periodicity of the Fe clusters can be controlled artificially by the reconstruction of the GaAs seed layer surface. These uniform Fe nano clusters on the c(4x4) reconstructed GaAs(100) surface, as seen in the Fig. 1, are expected to show new magneto-optical properties due to the 3-dimensional quantum size effect.

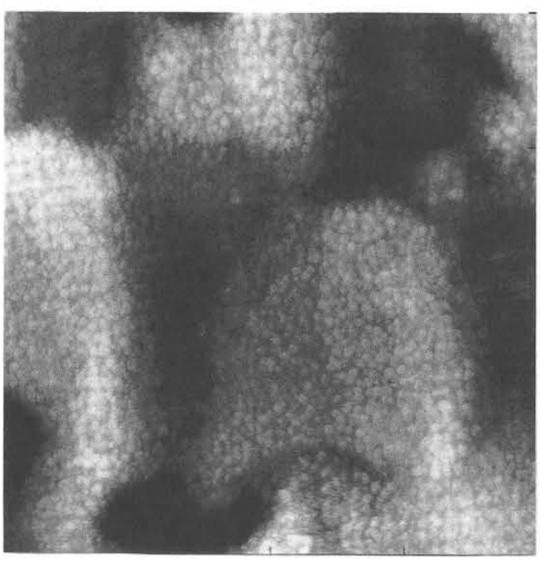


Fig. 3 100x100 nm^2 STM image of 0.8ML Fe grown on the Te stabilized (2x1) reconstructed GaAs(100) surface taken in a constant current mode with a 100pA tunneling current.

4. Conclusions

Nanometer size clusters of Fe on the c(4x4) reconstructed GaAs(100) surface was observed by STM at RT. It is suggested that the Fe clusters on the c(4x4) reconstructed GaAs(100) surface is closely related to the c(4x4) reconstruction, and the nucleation of the Fe cluster occurs at a specific position within the surface unit cell of the c(4x4) reconstruction of the GaAs(100) surface.

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