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Surface structure of silver thin films on In_2O_3:Sn and Al_2O_3[†]

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Abstract. Surface structure of thin silver films (200 Å) on two technologically important films, indium tin oxide (ITO) and aluminium oxide, has been studied using scanning tunneling microscope. ITO films were prepared by reactive electron beam evaporation. Aluminium oxide films were prepared by oxidizing 2000 Å thick aluminium films evaporated on to H_2 terminated single crystal silicon substrates. The surface structure of silver on ITO and aluminium oxide appeared to be same and was characteristic of Stranski–Krastanov type. The observed asymmetry in the island shape was attributed to the anisotropic nature of the strain fields surrounding the nucleation centres.

Keywords. STM; ITO; thin films.

1. Introduction

The growth and characterization of metal films especially on semiconductor substrates is of paramount importance. From a technological point of view, metal–semiconductor contact (Kaiser and Bell 1988; Kubby and Greene 1994) is the basic aspect of any semiconductor based device. As the size of the device is decreased, the structure of the metal over layer as well as its interface with the semiconductor, will have a profound influence on the electronic properties of a device. A complete study of the structure and interface characteristics of metal–semiconductor systems is therefore essential. From a fundamental point of view, a detailed knowledge of the surface morphology is required for understanding the nucleation and growth mechanisms. Of the different techniques available for probing the surface structure, STM (Weisendanger 1994) provides greater insight due to its capability to give three dimensional information.

In this paper we present our results on the surface structure of thin silver film on ITO. These results form the first part of a more detailed study of Ag/ITO system. The choice of the metal over layer is limited as the STM images are acquired under ambient conditions. Silver, being less susceptible to oxidation offers a simple system that can be studied with confidence in ambience. Tin doped indium oxide (ITO) (Hamberg and Granqvist 1986) is a transparent degenerate *n*-type semiconductor and finds application as an excellent solar cell and window coating material. We also present here our observations on Ag on an insulator, viz. aluminium oxide film. Thermally grown aluminium oxide films have been widely used as a model substrate for many fundamental studies (Komiyama *et al* 1994).

2. Experimental

The experiments were carried out in a Leybold Hereaus turbomolecular pump backed vacuum system. Thin silver films were deposited on ITO and aluminium oxide by

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evaporating pure silver wire from a tungsten boat. The base pressure during the deposition was about 10^{-6}mbar. Film thickness was monitored using INFICON Quartz crystal thickness monitor. A low deposition rate of about 3 Å s^{-1} was used. The thickness of the film was about 200 Å.

Aluminium oxide was formed by first depositing about 2000 Å thick aluminum film onto H_2 terminated single crystal silicon substrate and then exposing it to ambience. This results in the oxidation of aluminium and the formation of about 50 to 100 Å thick aluminum oxide. ITO films were formed by reactive electron beam evaporation under an oxygen atmosphere. ITO pellets (5 wt%) were evaporated using an electron gun in an oxygen partial pressure of about 5×10^{-4}torr. Single crystal silicon with thermal oxide was used as the substrate. Typical deposition rate was 2 Å s^{-1}. The substrate

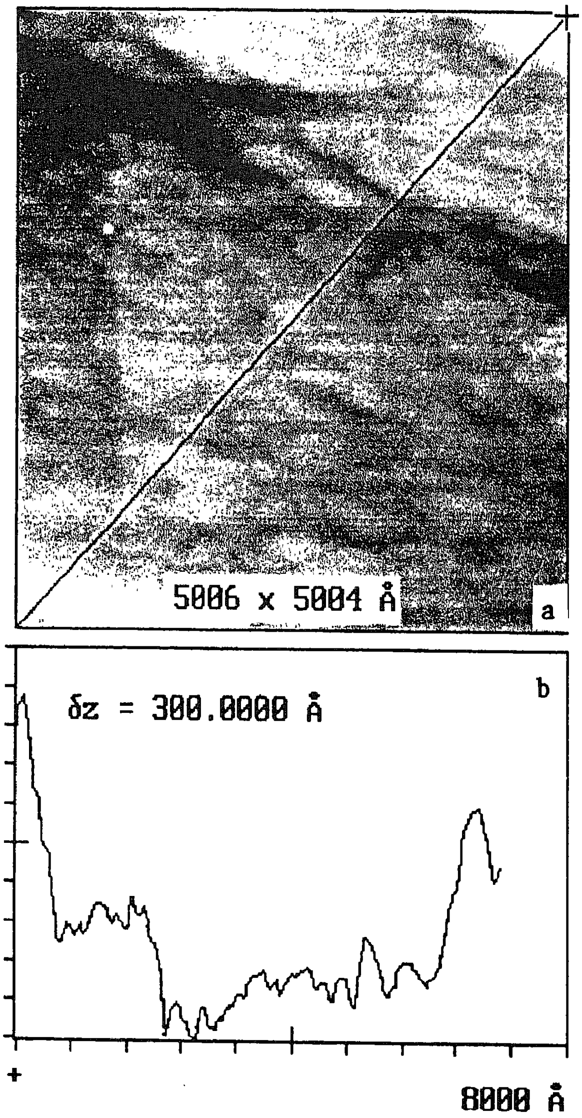


Figure 1. (**a**) STM topograph of Ag film on ITO and (**b**) line scan taken along the diagonal as shown in (**a**).

temperature during growth was 300°C. The film thickness was about 1500 Å. Optical absorption measurements showed the films to have a transparency of about 85% near the fundamental edge.

STM measurements were made using a commercial instrument (type UHV-635) from RHK Technologies, USA. The topographs were acquired at constant current mode. Typical sample bias was 300 mV and the tunneling current was in the range from 0·3 to 1 nA. Chemically etched (Rao *et al* 1991) tungsten wire and mechanically cut Pt–Ir wire were used as the tip in STM. Extreme care was taken to avoid any tip induced artefact. The acquired STM image is a convolution of the tip and sample profiles. In order to get true topograph of the sample, the tip profile should be deconvoluted. However, a satisfactory procedure has not yet been developed to accomplish this. In the present study, a large number of tips were used and images which were similar in shape were only taken. Images of a particular area showed similar features upon repeated scanning, indicating that the tip did not get damaged while scanning the surface. Since imaging was done in air the sample surface may be covered with a few layers of adsorbates. However, with sufficient bias, tunneling current could be established. We believe that the changes caused by the adsorbates are uniform all over the surface and the data represents true surface features. Further, the effect of adsorbates would be pronounced only when atomically resolved images are taken.

3. Results and discussion

Figure 1a shows a typical topograph of silver film on ITO. The thickness of the film is 200 Å. The scan area is 5000 Å × 5000 Å. The surface structure shows macroscopic terraces or steps. A line profile taken diagonally illustrates this structure (figure 1b)

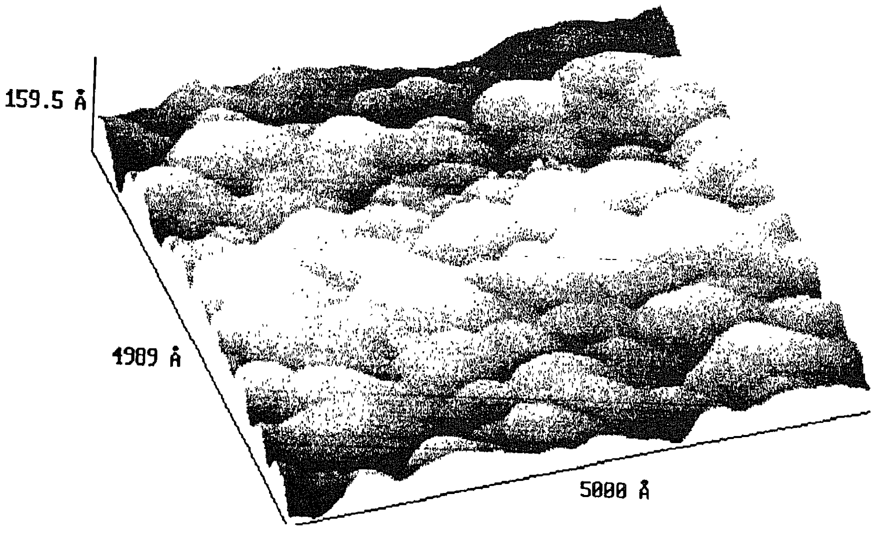


Figure 2. Surface structure of Ag on ITO showing clearly the formation of islands. The scan area is 498·9 nm × 500 nm.

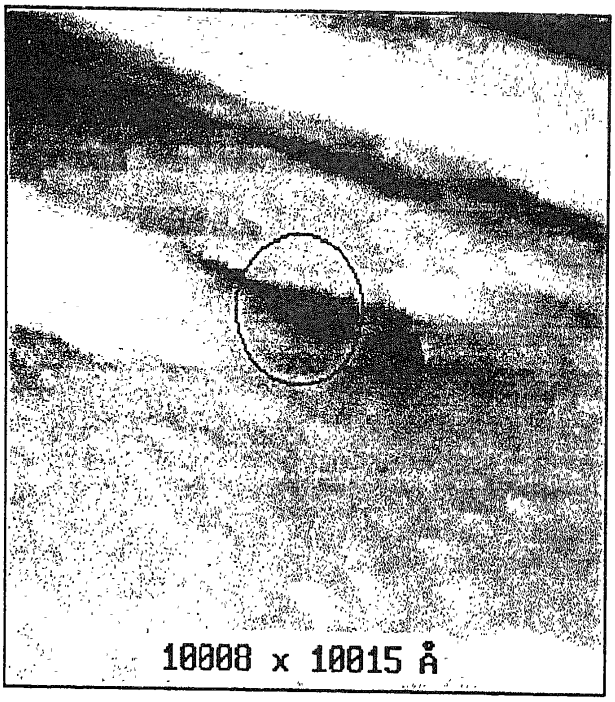
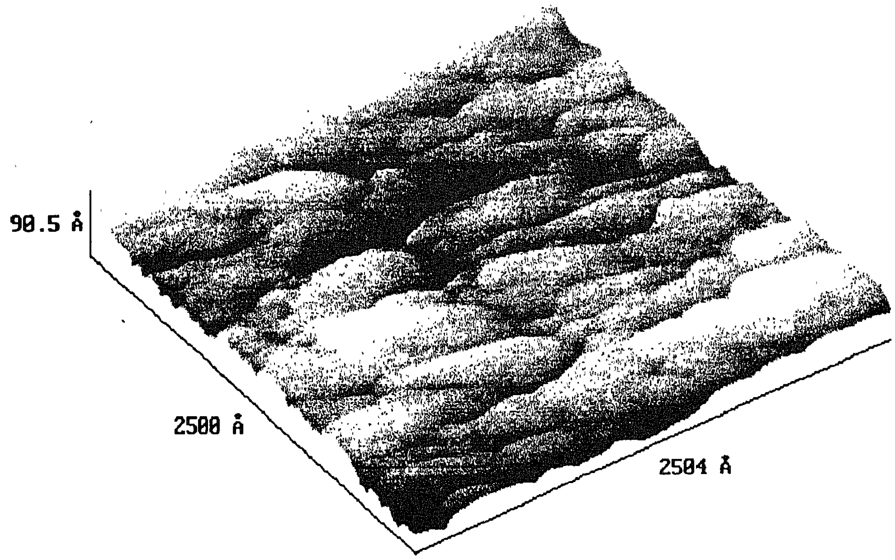


Figure 3. Typical large area (1000·8 nm × 1001·5 nm) scan of Ag on ITO. The well like feature is marked by the circle. Details are given in the text.

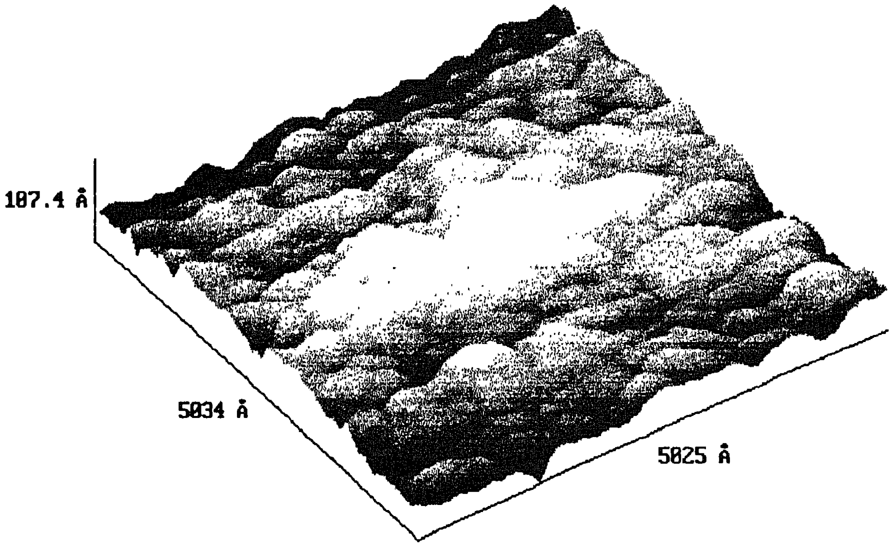
clearly. The straight line in figure 1a indicates the direction along which the line profile is taken. The presence of four terraces can be identified from the line profile. Only two of the terraces are clearly resolved, as the other two fall beyond the scanned area. The vertical height difference between the highest and lowest step is about 300 Å. Images taken from different regions of the sample presented similar terraced structure. The terraces are not entirely flat. A closer look at the figure shows the presence of two dimensional islands on the terraces. The islands are not randomly placed. A slight order in the orientation of the islands can be noticed from the figure.

Figure 2 shows the surface structure taken on an individual terrace. The dimensions of the image is 2500 $Å^2$. The figure shows a distribution of 2 dimensional islands. The islands are found to be rather anisotropic, i.e. they show a strong deviation from the spherical shape and are elongated. In addition, they appear to be oriented in a particular direction. The measured asymmetry in the shape of most of the islands is more than 70%. The height of the islands is about 100 Å.

In general when condensed from vapour phase on to a cold substrate, the growth is expected to follow one of the following three well known modes (Chopra 1969): Layer by layer growth, layer by layer followed by 3D islands and 3D island growth. A particular growth mode prevails over the other depending upon the magnitude and sign of the sum of the interface and surface energies of the condensate and the substrate. In addition, kinetic processes like surface diffusion and miscibility may also be deciding factors during the initial stages of nucleation. The observed growth mode looks rather similar to the growth of metal films especially on semiconducting surfaces. This kind of growth is characteristic of Stranski–Krastanov growth, viz. layer by layer followed by



a



b

Figure 4. (**a**) Typical STM topograph of Ag film on aluminium oxide and (**b**) a large area scan of Ag on aluminium oxide. Note the similarity between this and figure 2.

3D growth. In such a case, initially the condensate completely covers the surface and grows as layers up to few monolayers. This is then followed by the 3D growth. These 3D structures may then join to form the terraced structure.

The images also showed the presence of large well like structures (see figure 3) which appear as dark regions in the figures. In figure 3, the encircled area depicts one such region. The depth of this indentation is about 200 Å. This may indicate the presence of a true hole or a place with a change in local electron density or a combination of both. If it is due to the changes in local electron density of states, it may be due to the presence of a non-metallic region in an otherwise metallic background (Van De Leemput *et al* 1988). This is quite possible because the substrate is a degenerate semiconductor. When the STM tip moves over a region with low electron density, there will be a decrease in the tunnel current. Since the images are acquired in the constant current mode, the tip will be pulled towards the surface till the tunnel current attains the set value. In the topograph this will appear as a hole. Another possibility is to consider the local changes in the barrier height (Gimzewski *et al* 1985). However corrugations arising out of local barrier height variations cannot exceed 1 to 2 nm and so will not account for the large height variations observed.

Figures 4a and b show the topograph of silver film on aluminium oxide. The scan area of figure 4a is 2500 × 2500 Å and that of 4b is 5000 × 5000 Å. The presence of islands can be seen clearly in the image. The islands are elongated and appeared to be oriented. The island structure looks rather similar to that of Ag/ITO. However, the surface roughness (about 108 Å) is lesser when compared to Ag on ITO (about 160 Å). Further the surface did not present the terraced structure observed in Ag/ITO. Generally, the structure of an island follows the symmetry of the strain fields around the nucleation centres. The observed elongated shape of the islands may be due to the anisotropic nature of the strain fields.

4. Conclusion

In conclusion we have studied the structural aspects of the system Ag/ITO, which forms a part of our investigations on the Ag/ITO Schottky barriers. The growth pattern appears similar to the Stranski–Krastanov type, which is characterized by layered plus island growth. The asymmetry in the island shape may reflect the anisotropic nature of the strain fields surrounding the growth centres. The growth of Ag on aluminium oxide looks largely similar to Ag on ITO.

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