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Scanning AES Studies of Electromigration of Ag, In and Sb Ultrathin Films on Si

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The electromigration of a pad of Ag, In, Sn and Sb ultrathin film with a thickness of several monolayers on Si (111) 7 X 7 surface was investigated by scanning Auger spectroscopy. These thin films exhibited peculiar movement entirely different from the conventional electromigration in the ordinary film. The transport of materials is considered to be associated with relaxation of structural instability inherent in the evaporated film.

1 Introduction

We found[1)] that a pad of In ultrathin film with a thickness of several monolayers was easily transported toward cathode on an atomically flat and clean surface of Si wafer which was carrying dc current. This phenomenon can be regarded as a type of electromigration. However, it proved to be entirely different in many respects from the conventional electromigration so far studied in bulk materials[2)] and ordinary thin films.[3)] For instance, the direction of material transport is toward cathode for the ultrathin film while it is in the opposite direction for the ordinary film. The mobility of In atom in the ultrathin film is three orders of magnitude higher than that of the ordinary film. In the process of electromigration the ultrathin film develops peculiar morphology which has no counterpart in the ordinary film. One can expect that this new type of electromigration would become of great importance in fabrication and operation of those microelctronic devices which involve ultrathin film directly contacted to clean surface of semiconductor.

This paper represents an extension of the scanning Auger electron spectroscopy studies to Ag, Sn and Sb ultrathin films on Si with an aim of examining the universality of this electromigration. These elements, belonging to the fifth row of the periodic table, were employed since they not only form stable overlayer but also have sufficient Auger sensitivity. Scanning Auger electron spectroscopy is the most powerful method to observe the movement of a small area of ultrathin film of such elements since one can observe the distribution of the thickness in the area of the film if the thickness of the film is within several monolayers.

In the following sections, a brief discription of experimental method and some results with discussion are given.

2 Experimental

The preparation of the sample and subsequent observations were made in situ in an ultrahigh vacuume of base pressures less than 5 X 10^{-8} Pa. The substrate used (typically 10 X 2 X 0.4 mm^3) was cut from a Si (111) wafer and suspended by two strips of tantalum sheet at both ends. The strips also served as electrodes supplying current needed for electromigration as well as thermal cleaning. A small rectangular pad of the film approximately 100 X 150 μm^2 was evaporated through a mask on a thermally cleaned Si (111) 7 X 7 surface at room temperature. The cleaning was done by Joule heating at 1200 ^{o}C for more than several minutes. The thickness of the film was

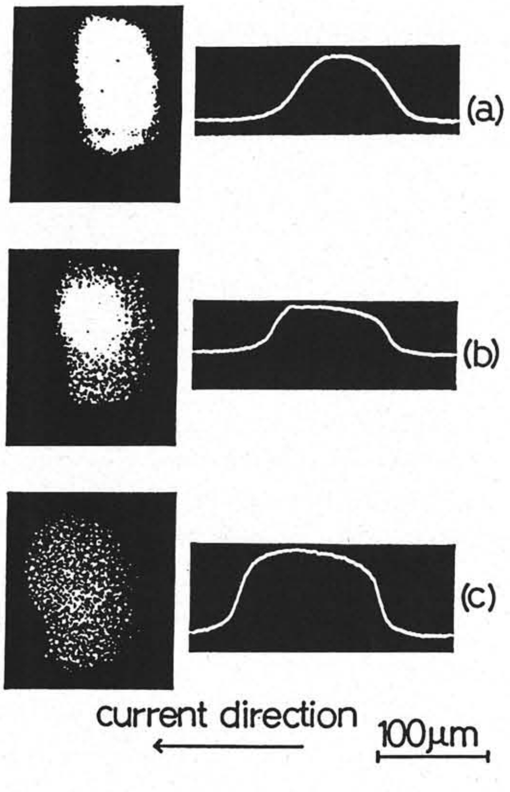

Fig. 1. Auger maps (left side) and Auger line analysis (right side) of the Ag pad with a thickness of 2 monolayers. (a) Before the application of dc supply. (b) After the application of dc supply of 20 V in voltage and 50 mA in current for 45 minutes. The temperature of the substrate was raised to 170 °C by the dc supply. (c) After further application of dc supply of 15 V in voltage and 100 mA in current for 60 minutes. The temperature of the substrate was raised to 200 °C.

monitored by a quartz microbalance. The spacial distribution of the element in the film was obtained by the scanning analysis of the Auger peak height at the MNN transitions (351, 430 and 454 eV for Ag, Sn and Sb, respectively) with Physical Electronics 590 Scanning Auger Microscope. The diameter of the incident electron beam was made no more than 1 μm.

3 Results and discussions

Common to all the film material examined, a significant transport of the material was observed for the film with a thickness of more than approximately one monolayer. However, the movement, if any, was scarcely detected for the film with a thickness of less than one monolayer. Ac (50 Hz) supply gave no contribution to the electromigration except isotropic movement due to Joule heating. The direction of the electromigration by dc supply proved to be toward cathode for Ag and Sn as for In, while Sb seems to have moved in the opposite direction. In the process of the movement, the film exhibited a wide variety of morphology from material to material as described below.

The movement of a Ag pad with a thickness of 2 monolayers are represented by Auger maps and Auger line analysis in Fig. 1. The edge of the pad on cathode side moved approximately uniformly to the

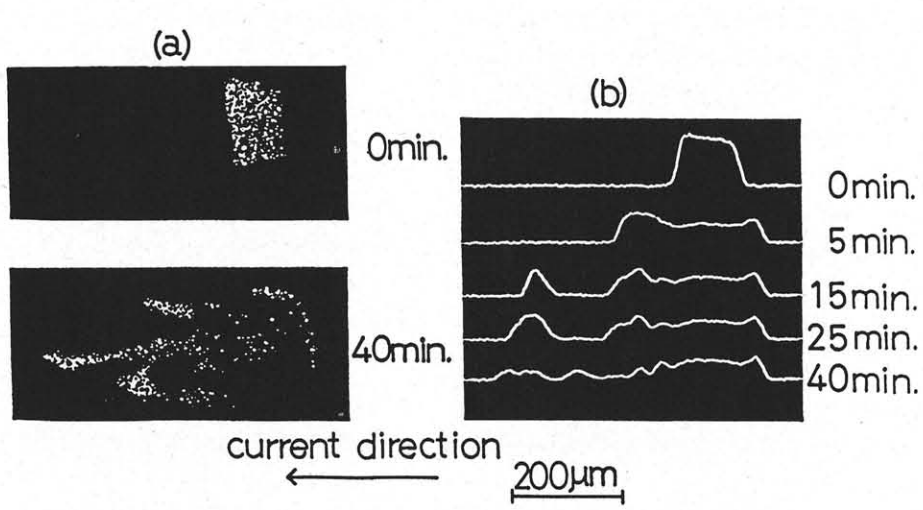

Fig. 2. Auger maps (a) and Auger line analysis (b) of the Sn pad with a thickness of 4 monolayers. The time of the application of dc supply of 20 V in voltage and 50 mA in current is indicated. The temperature of the substrate was raised to 170 °C by the dc supply.

same direction as current. The edge of the other side remained substantially unmoved as seen in the Auger line analysis. This is not apparent in the Auger maps on account of poor adjustment of the conversion of the Auger peak height to brightness on oscilloscope display.

A typical example of the observed movement of the Sn pad with a thickness of 4 monolayers are shown in Fig. 2. In contrast to the uniform and slow movement of Ag, Sn moved nonuniformly and much faster. Here Sn behaved like a film of water on a tilted glass plane. The direction of the movement of Sn is toward cathode, too. In ordinary films Sn moves toward anode.[4),5)] A slight movement of the edge on the anode side was observed after the initial application of dc supply. However, no further progress was succeeded. This movement proved to be isotropic spreading due to the initial Joule heating. It should be noted that the pad did not move at all under the application of dc current of 10 mA for quite a long time. Here the temperature of substrate was raised to 110 °C by the dc supply.

Auger line analysis of the Sb pad with a thickness of 4 monolayers are indicated in Fig. 3. On close examination, Sb seems to have moved slightly toward anode. The allowed dc current to drive the Sb pad was limited on account of quite a high vapor pressure of the element at not so high temperatures and was 15 mA at most. Anyway it is evident that the electromigration of Sb is very weak compared with that of the other elements studied.

The distance over which the edge of the pad proceeded is plotted as a function of the time during which dc current was carried in Fig. 4. There is a common tendency for all the elements that material was transported initially at a constant velocity followed by slowing down.

In the previous paper[1)] we stated that the electromigration of the In ultrathin film was associated with relaxation of structural instability inherent in the evaporated film. That is, the evaporated film moves from the initial metastable amorphous phase into the more stable Stranski-Krastanov (island-on-layer) structure in the process of the electromigration. Thereby an In

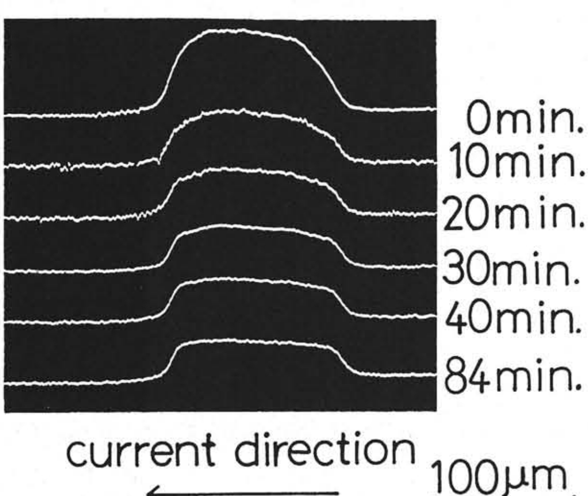

Fig. 3. Change in the Auger line analysis of the Sb pad with a thickness of 4 monolayers with time of the application of dc supply of 38 V in voltage and 15 mA in current. On close examination it proved that the pad slightly moved toward anode. The temperature of the substrate was raised to 130 °C.

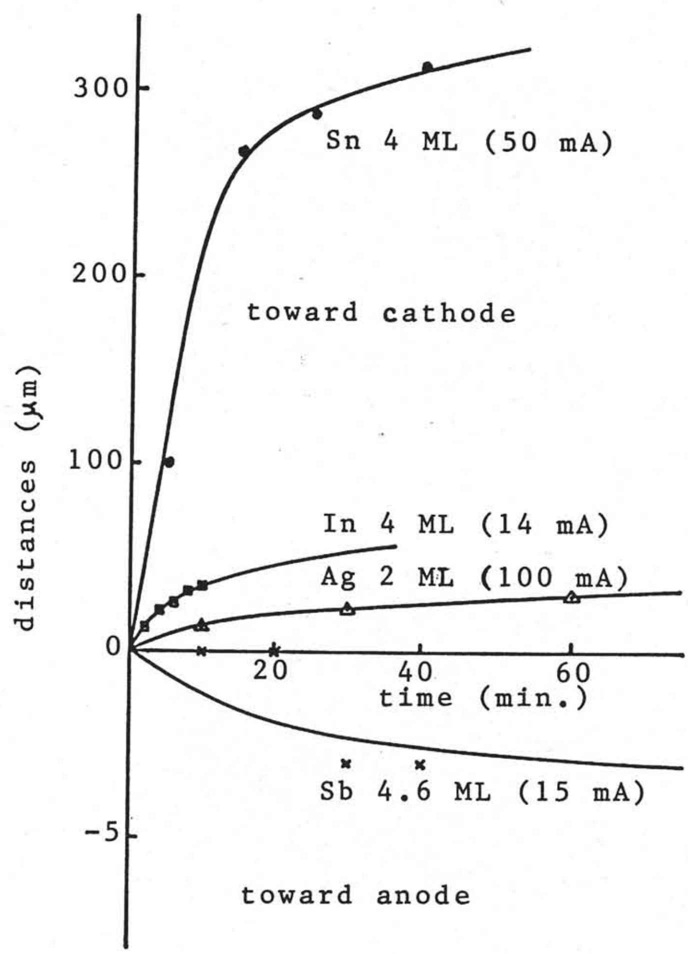

Fig. 4. Distances over which the pads of 4 elements were transported as a function of time of the application of dc supply. Note the change in scale of the ordinate.

layer of 1.2 monolayers in thickness advanced into the clean surface of the substrate maintaining its thickness constant due to quite a high mobility of In atom just on this layer.

Likewise in the present study the movement can generally be regarded as a drift in the process of relaxation of structural instability. Therefore the velocity of the movement decreases with the approach to the stable structure. Dc supply contributes not only to drift but also relaxation through drift itself as well as heating.

In the case of Ag film on Si (111) the island-on-layer structure is favored as a stable form.[6] This implies that Ag is easy to move just on the layer. The evaporated film is considered to have meta-stable structure. Thus electromigration can be expected to occur when this structure is managed to move into the more stable island-on-layer structure. This was the case as described above.

Slowing down of the velocity of the transport with stabilization of structure is indicated in

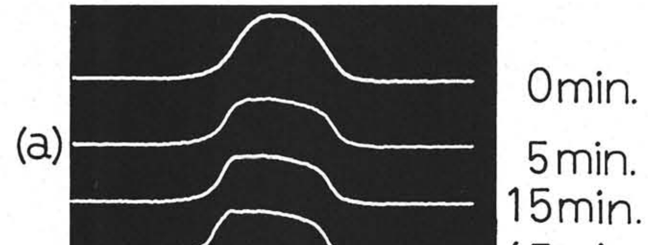

Fig. 5. Changes in the Auger line analysis of the Ag pad with a thickness of 2 monolayers with time of the application of (a) dc supply of 50 mA in current (170 ^{o}C) and (b) ac supply of 50 mA in addition to dc one of 50 mA (184 ^{o}C).

Figs. 5 and 6. Here it is evident that ac supply in addition to dc one rather decreases the velocity of the movement in spite of temperature increased. This is due to the effect of stabilization of structure exceeding the effect of increased mobility at higher temperature.

As is well known, Sn exhibits a transition from β- to γ-phase at 161 ^{o}C with increasing temperature. The fact that Sn showed the electromigration at 200 ^{o}C while it did not move at all at 110 ^{o}C is considered to be related with this phase transition. That is, since the film on evaporation has a structure close to β-phase, there is no structural instability at temperatures below the transition point. On the other hand, above the transition temperature the initial evaporated phase changes into γ-phase, which accompanies the violent movement as was observed.

Judging from the observed relation of Sb Auger peak height with the thickness, Sb film is formed in the layer-by-layer mode. Thus there is little instability inherent in the film on evaporation. There is the reason why the movement of the Sb pad was so slight.

References

1. H. Yasunaga, Y. Kubo and N. Okuyama: Jpn. J Appl. Phys. 25 (1986) L400.
2. H. B. Huntington: Diffusion in Solids (Recent Developments), ed. by A. S. Nowick and J. J. Burton (Academic Press, New York, 1975), Chap. 6.
3. F. M. d'Heurle and P. S. Ho: Thin Films-Interdiffusion and Reactions, ed. by J. M. Poate, K. N. Tu and J. W. Mayer (John Wiley, New York, 1978), Chap. 8.
4. H. M. Breitling and R. E. Hummel: J. Phys. Chem. Solids, 33 (1972) 845.
5. P. H. Sun and M. Ohring: J. Appl. Phys. 47 (1976) 478.
6. J. A. Venables, J. Derrien and A. P. Janssen: Surf. Sci. 95 (1980) 411.