The application of TEM in Nanocrystal formation process

Ki-Bum Kim, Tae-Sik Yoon, Dae-On Kim, and Hyun-Mi Kim
School of Materials Science and Engineering, Seoul National University

I. Introduction

Nowadays, the nanocrystal or quantum dot is widely investigated for the application to nanodevice, such as single electron device, optical device, etc.[1][2] Also, in the thin film deposition, the importance of the nucleation and growth behavior increases significantly because the nucleation and growth behavior affect the properties of thin film.[3] For the analysis of nanocrystal or quantum dot formation and initial stage of thin film growth, transmission electron microscope(TEM) is thought to be very useful since it has highly resolving capability with atomic resolution.

In this paper, a few examples of the utilization of TEM for the analysis of nanocrystal or quantum dot formation and initial stage of thin film growth will be shown.

II. TEM analysis of $Si_{0.7}Ge_{0.3}$ nanocrystal formed by low pressure chemical vapor deposition(LPCVD) on SiO_2 substrate

Amorphous $Si_{0.7}Ge_{0.3}$(~4 nm) thin layer was deposited on 4-nm-thick thermally growth SiO_2 substrate by LPCVD using Si_2H_6 and GeH_4 at 375 oC, 1 Torr. After the deposition of $Si_{0.7}Ge_{0.3}$ thin layer, SiO_2 was deposited to a thickness of 18 nm by LPCVD using Si_2H_6 and O_2 gases at 375 oC, 1 Torr. This structure of CVD-SiO_2(18 nm)/amorphous-$Si_{0.7}Ge_{0.3}$(~4 nm)/thermal-SiO_2(~4 nm) on Si substrate was annealed at 800 oC for 10 minutes either in a purged N_2 environment in a conventional atmospheric quartz tube furnace, or in a vacuum with the vacuum level < 10^{-6} Torr.

Figure 1 shows the cross-sectional high-resolution TEM image of the as-deposited structure. As shown in Fig. 1, the as-deposited Si0.7Ge0.3 was deposited as islands(nanocrystals) with the size of about 4 nm. To measure the size and spatial density of nanocrystals, plan-view TEM analysis was carried out after annealing either at purged N2 environment or in a vacuum, whose results are shown in Fig. 2.

Figure 2(a) and 2(b) are the plan-view TEM bright-filed images of nanocrystals annealed at 800 oC for 10 minutes in a vacuum and in a purged N2 environment, respectively. From these figures, it can be shown that Si0.7Ge0.3 is separated individually. In the case of vacuum annealing, the average diameter and the spatial density of nanocrystals are about 3.6 nm and about 1.5´1012/cm2, respectively. Also, in the case of purged N2 annealing, the average diameter of nanocrystals is about 4.9 nm and their spatial density is about 3.8´1011/cm2, which is smaller than that of nanocrystals annealed in a vacuum by approximately four times.

As shown in figures, it is possible to analyze the formation of nanocrystals, their size and spatial distribution, and their crystalline structure by using TEM.

III. TEM analysis of the initial growth stage of Au thin film deposited by sputtering on SiO2 substrate

The initial growth stage of sputter-deposited Au thin film was investigated. Au thin film with a nominal thickness of 0.5, 1, and 2 nm was deposited at sputtering power of 100 W and pressure of 10 mTorr. The size and structure of nuclei at the initial stage of Au thin film were characterized by using conventional and high-resolution TEM.

Figure 3(a) and 3(b) are the plan-view TEM bright-filed images of initial Au nuclei with a nominal thickness of 1 and 2 nm, respectively. From these figures, it can be shown that Au thin film deposited on SiO2 is grown as island growth mode, and the coalescence between nuclei appears as a film thickness is increased. Due to the coalescence between nuclei, the size of clusters is increased and the density of clusters is decreased as a film thickness is increased. We used high-resolution TEM analysis for the highly precise observation of nucleation and coalescence behavior at initial stage of film deposition.

Figure 4 is the high-resolution TEM image of Au clusters with a nominal thickness of 0.5 nm. This figure shows that some clusters are single-crystalline and the others are poly-crystalline having various defects. From this, it can be confirmed that the cluster coalescence and defect formation in nanoscale clusters appear at the initial stage of film deposition.

IV. Summary

TEM is very useful in the investigation of nanoscale quantum dots or initial stage of thin film deposition such as the behavior of nucleation, growth, and coalescence between clusters. With TEM, we could analyze the nanocrystal formation and size and spatial distribution of nanocrystals in the deposition of amorphous Si0.7Ge0.3 thin film. In addition, the initial growth stage of Au thin film such as island growth and coalescence behavior could be confirmed very precisely with TEM.

References

[1] Tae-Sik Yoon, Jang-Yeon Kwon, Dong-Hoon Lee, Ki-Bum Kim, Seok-Hong Min, Dong-Hyuk Chae, Dae Hwan Kim, Jong Duk Lee, Byung-Gook Park, Hwack Joo Lee, J. Appl. Phys. **87**, 2449(2000)

[2] S. Yoon, Y. Moon, T. -W. Lee, E. Yoon, and Y. D. Kim, Appl. Phys. Lett. **74**, 2029 (1999)

[3] Myung-Kwan Ryu, Seok-Min Hwang, Tae-Hoon Kim, Ki-Bum Kim, and Seok-Hong Min, Appl. Phys. Lett. **71**, 3063(1997)

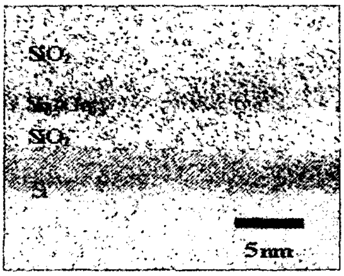

Fig. 1. Cross-sectional high-resolution TEM image of the as-deposited structure.

Fig. 2. Plan-view TEM bright-filed images of nanocrystals annealed at 800 oC for 10 minutes (a) in a vacuum and (b) in a purged N2 environment.

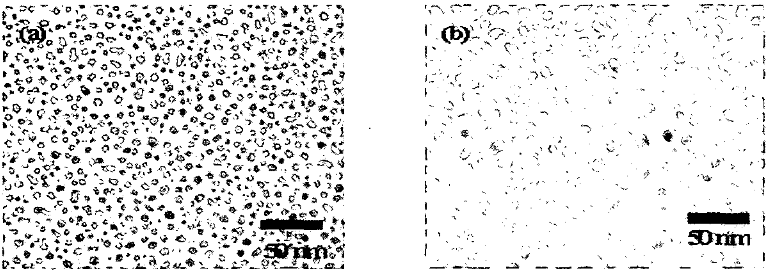

Fig. 3. Plan-view TEM bright-filed images of initial Au nuclei ; (a) nominal thickness of 1 nm and (b) 2 nm.

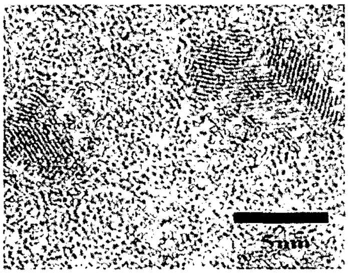

Fig. 4. High-resolution TEM image of Au clusters with a nominal thickness of 0.5 nm.