Effects of underlying metals on textures of plated Au films on GaN

Kazuhiro Maeda, Koichiro Nishizawa, Daisuke Suzuki, Toshihiko Shiga and Hitoshi Watanabe
High Frequency & Optical Device Works, Mitsubishi Electric Corporation,
4-1, Mizuhara, Itami, Hyogo, 664-8641, Japan
TEL +81-72-784-7401, FAX +81-72-780-2683, E-mail: Maeda.Kazuhiro@cw.MitsubishiElectric.co.jp

INTRODUCTION

AlGaN/GaN high electron mobility transistors (HEMT) which are attracted as a key device in the future are studied for more high-voltage and more high-power applications than GaAs-HEMT[1,2]. In metal interconnections on compound semiconductors, for example GaAs and GaN, evaporated and electroplated Au films are applied widely. In many case, Au thin films tend to have (111) orientation which is the close-packed plane of a face-centered cubic (FCC) structure. Atomic arrangement of Au(111) face which is a hexagonal lattice differs from those of GaAs(001) face which is a square lattice. However, atomic arrangement of Au(111) face consists with that of GaN(0001) face which is a hexagonal lattice. Therefore, in this work, the crystallization of evaporated Au films on GaAs(001) and GaN(0001) were investigated. Moreover, the effects of the underlying evaporated metals on textures of plated Au metals were examined.

EXPERIMENTAL

GaAs and SiC/AlN/GaN/AlGaN wafers were used as the substrate, and metal films were deposited on GaAs(001) and AlGaN (0001) face. The substrate surfaces were cleaned by organic solvent and HCl to remove contamination and a natural oxide layer. Metal films were deposited onto the substrates by EB evaporation at room temperature below 4.5×10^{-4} Pa. Ti/Au and Ti/Nb/Ti/Pt/Au structures were grown on substrates. The thicknesses of Ti/Au and Ti/Nb/Ti/Pt/Au multilayers were 50/1000 and 50/50/50/30/1000 (all in units of nm). It should be noted that GaN and AlGaN have hexagonal wurtzite structures, Ti has a hexagonal close-packed structure (HCP), Au and Pt have FCC structures and Nb has a body-centered cubic structure (BCC). The crystal structures of the films were studied using x-ray diffraction (XRD) and transmission electron microscope (TEM). Next, Au films were grown by electroplating using current density of 4mA/cm^2 on evaporated films. Surfaces of the plated Au films were observed by photo microscopy. The film structures and the grain sizes were investigated using cross-section scanning electron microscope (SEM).

RESULTS & DISCUSSION

2θ-ω scan of XRD were carried out on each sample. In AlGaN/Ti/Au, only peaks related to Au(111) plane are observed as shown in Fig. 1. It is suggested that the Au layer is completely oriented to the (111) direction along AlGaN(0001). Although, in GaAs/Ti/Au and AlGaN/Ti/Nb/Pt/Au, the Au layers are preferentially

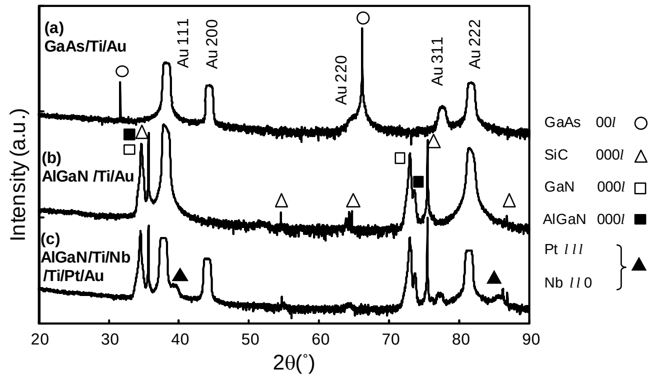

FIG. 1. 2θ-ω scan profiles of (a) GaAs/Ti/Au, (b) AlGaN/Ti/Au and (c)AlGaN/Ti/Nb/Ti/Pt/Au

oriented along the (111) plane, are different crystal planes observed.

The Φ-scan technique of XRD can determine the symmetry and orientation of films. Figure 2 shows results of the Φ-scan on each sample. In GaAs/Ti/Au, no diffraction peak is observed. This indicates that the Au layer on GaAs is randomly oriented the in-plane direction. In AlGaN/Ti/Au, a total of twelve Au (220) diffraction peaks are observed. Six main peaks of the peaks are at intervals of angle of 60º in agreement with AlGaN($10\bar{1}0$). In AlGaN/Ti/Nb/Ti/Pt/Au, the diffraction peaks which are displaced from the main Au (220) diffraction peaks observed by a rotation angle of 30º and have a wider half-width and a lower intensity. As a result, although a lattice mismatch between AlGaN(0001) and Au(111) is large (=6.1%), Au layer grows epitaxially on AlGaN. Additionally, it is suggested that the crystalline of Ti/Au depends on the Nb layer which has a BCC structure.

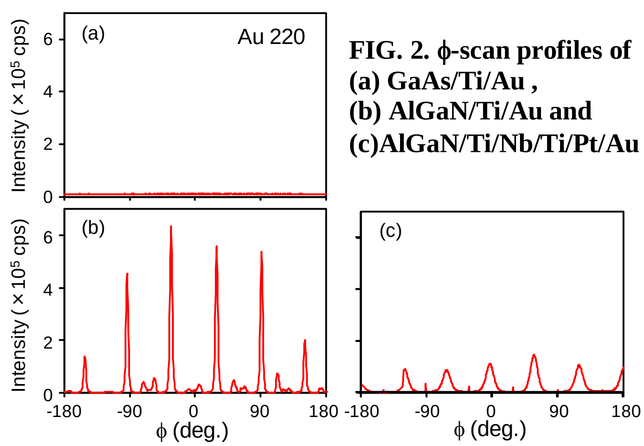

FIG. 2. ϕ-scan profiles of (a) GaAs/Ti/Au , (b) AlGaN/Ti/Au and (c)AlGaN/Ti/Nb/Ti/Pt/Au

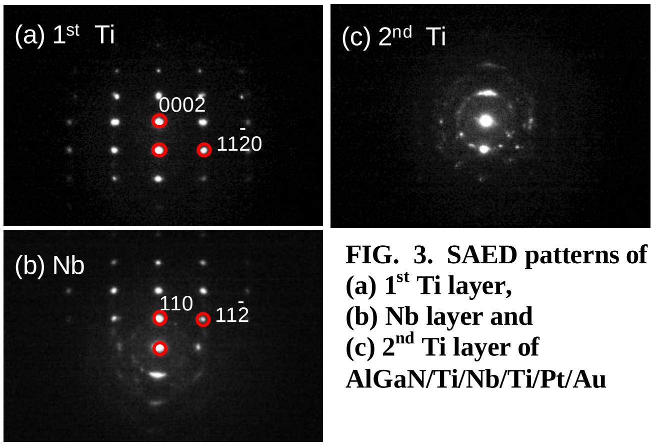

FIG. 3. SAED patterns of (a) 1st Ti layer, (b) Nb layer and (c) 2nd Ti layer of AlGaN/Ti/Nb/Ti/Pt/Au

To reveal the role of Nb in detail, selected area electron diffraction (SAED) patterns of Ti/Au and Ti/Nb/Ti/Pt/Au on AlGaN were measured using TEM. Figures 3(a), (b) and (c) show SAED patterns of 1st Ti layer, Nb layer and 2nd Ti layer of Ti/Nb/Ti/Pt/Au, respectively. The diffraction patterns of 1st Ti layer of Ti/Nb/Ti/Pt/Au are assigned to a HCP structure in accordance with those of Ti/Au. Since the SAED pattern of Nb layer shows spot and ring patterns, it is suggested that a part of the Nb layer is randomly oriented. The epitaxial relations of the 1st Ti and the Nb layers are AlGaN[0001]//Ti[0001]//Nb[110] for the out-of-plane orientation and AlGaN[11$\bar{2}$0] //Ti[11$\bar{2}$0]//Nb[1$\bar{1}$0] for the in-plane orientation. On the other hand, in the SAED pattern of the 2nd Ti layer, ring patterns are observed. Therefore, it is found that the 2nd Ti layer is randomly oriented. Based on the results, since the atomic arrangement of Ti(0001) which has a hexagonal lattice differs from that of Nb(110) which has a rectangular lattice, the atomic arrangement of the 2nd Ti layer on Nb(110) is more random than that of 1st Ti layer on AlGaN (0001).

Next, Au films were electroplated on evaporated films. Figure 4 shows that the plated Au films on GaAs/Ti/Au and AlGaN/Ti/Nb/Ti/Pt/Au have uniform surfaces. On the other hand, a surface of the plated Au film on AlGaN/Ti/Au exhibits peculiar appearances.

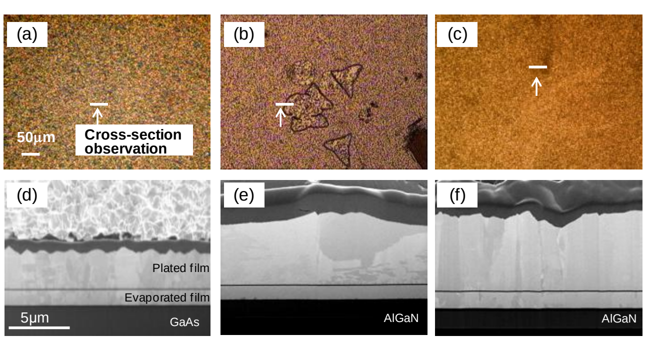

FIG. 4. Surface morphologies of (a) GaAs/Ti/Au, (b) AlGaN/Ti/Au and (c)AlGaN/Ti/Nb/Ti/Pt/Au. Cross-section SEM images of (c) GaAs/Ti/Au , (d) AlGaN/Ti/Au and (e)AlGaN/Ti/Nb/Ti/Pt/Au

Thus, the microstructures of films were analyzed using cross-section SEM to investigate the peculiar appearances. The evaporated Au layers of GaAs/Ti/Au and AlGaN/Ti/Nb/Ti/Pt/Au have many grain boundaries as shown in Figs. 4 (d) and (f). The grain sizes of evaporated Au layers of GaAs/Ti/Au and AlGaN/Ti/Nb/Ti/Pt/Au and are 0.3 – 7.2 μm and 1.4 – 9.0 μm, respectively. The plated Au films on these samples also have many grain boundaries and small uneven surfaces. In contrast, the evaporated Au layer of GaN/Ti/Au has grain sizes of greater than 15 μm as shown in Fig. 4 (e). The plated Au film on it has large grains and the surface is smooth except the grain boundary. Therefore, it is found that the grain boundaries of the plated Au films depend on those of the evaporated Au layer. The grain sizes of plated Au films are smaller according to lower crystalline of evaporated Au films. In addition, Fig. 4 (e) shows that the peculiar appearance in AlGaN/Ti/Au corresponds to the grain boundary of the plated Au film. Therefore, it is suggested that since the plated Au film on the AlGaN/Ti/Au forms large grains, the grain boundaries arise as peculiar appearances.

In summary, when Au film is electroplated on Ti/Au layer which grows epitaxially on GaN, peculiar appearances occur at the surface to increase its grain sizes. When Nb layer is inserted between Ti layer and GaN in evaporated film, the atomic arrangements of Ti/Au are disturbed and grain sizes of the plated Au film on the evaporated film are smaller. As a result, the surface morphology is uniform as plated Au film on GaAs.

KEYWORD

GaN, Metallization, plating, evaporation, Au, Nb

REFERENCES

Reference

[1] A. Soltani, M. Rousseau, J.-C. Gerbedoen, M. Mattalah,
P. L. Bonanno, A. Telia, N. Bourzgui, G. Patriarche, A. Ougazzaden, and A. BenMoussa, vol.104, 233506, 2014

[2] A.V. Davydova, L.A. Benderskya, W.J. Boettingera, D. Josella, M.D. Vaudinb, K.-S. Changc, I. Takeuchic Applied Sureface Science vol.223, pp.24 - 29, 2004