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

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Abstract

The effects of the underlying metal on the textures of plated Au films on GaN were investigated using XRD, TEM and SEM. Here, Au/Ti and Au/Pt/Ti/Nb/Ti films were deposited by evaporating on GaAs(001) and AlGaN(0001)/GaN/AlN/SiC substrates. The X-ray results show that the Au layer in Au/Ti/GaAs orients randomly in-plane and, in Au/Ti/AlGaN, Au(220) faces the orient in parallel to AlGaN($10\bar{1}0$) in-plane. Those phenomena are interpreted by lattice mismatching. The atomic arrangement of an Au(111) face, which is a hexagonal lattice, differs from that of a GaAs(001) face which is a square lattice, on the other hand, the atomic arrangement of the Au(111) face corresponds to that of AlGaN(0001) which is a hexagonal lattice. Moreover, the Au layer in Au/Pt/Ti/Nb/Ti/AlGaN has lower crystallinity than that of Au/Ti/AlGaN because an Nb(110) face, which is a rectangular lattice, mainly grows on the AlGaN(0001) face. As the lattice mismatching gets large, the crystallinity of the evaporated Au layer becomes lower and the grain sizes are smaller. As a result, on plated Au films on Au/Ti/AlGaN, the grain sizes of the plated Au are more than 15 μm and the surface exhibits a peculiar appearance. In contrast, on Au/Pt/Ti/Nb/Ti/AlGaN and Au/Ti/GaAs, the grain sizes are smaller and the surface morphology is more uniform than Au/Ti/AlGaN.

INTRODUCTION

The AlGaN/GaN-HEMT, which is attractive as a key future device, has been studied for higher voltage and higher power applications than GaAs-HEMT [1, 2]. In metal interconnections on compound semiconductors, for example GaAs and GaN, evaporated and electroplated Au films are widely used. In many cases, Au thin films tend to have (111) orientation which is the close-packed plane of an FCC structure. The atomic arrangement of an Au(111) face, which is a hexagonal lattice, differs from that of a GaAs(001) face, which is a square lattice. However, the atomic arrangement of an Au(111) face corresponds to that of a GaN(0001) face, which is a hexagonal lattice. Indeed, it has been reported that Ni and Au which have an FCC structure epitaxially grow on GaN(0001) [3, 4]. 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 the textures of plated Au metals were examined.

EXPERIMENTAL

Here, GaAs and AlGaN/GaN/AlN/SiC wafers were used as the substrate, and metal films were deposited on GaAs(001) and AlGaN(0001) faces. 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 electron beam evaporation at room temperature below 4.5×10^{-4} Pa. The Au/Ti and Au/Pt/Ti/Nb/Ti structures were grown on substrates. The thicknesses of the Au/Ti and Au/Pt/Ti/Nb/Ti multilayers were 1000/50 and 1000/30/50/50/50 (all in units of nm). It should be noted that GaN and AlGaN have hexagonal wurtzite structures, Ti has a HCP structure, Au and Pt have FCC structures and Nb has a BCC structure. The crystal structures of the films were studied using XRD and TEM. Next, Au films were grown by electroplating using the current density of 4 mA/cm^2 on evaporated films. The surfaces of the plated Au films were observed by photo microscopy. The film structures and the grain sizes were investigated using a cross-section SEM.

RESULTS & DISCUSSION

Then 2θ-ω scans of XRD were carried out on each sample.

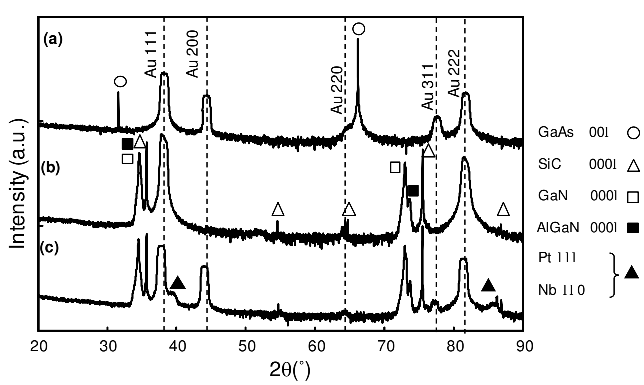

Fig. 1 2θ-ω scan profiles of (a) Au/Ti/GaAs, (b) Au/Ti/AlGaN and (c) Au/Pt/Ti/Nb/Ti/AlGaN.

In Au/Ti/AlGaN, only peaks related to the Au(111) plane, except for peaks from the substrates, were observed as shown in Fig. 1. It is suggested that the Au layer is completely oriented in the (111) direction along AlGaN(0001). Although, in Au/Ti/GaAs and Au/Pt/Ti/Nb/Ti/AlGaN, the Au layers are preferentially oriented along the (111) plane, different crystal planes are observed.

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

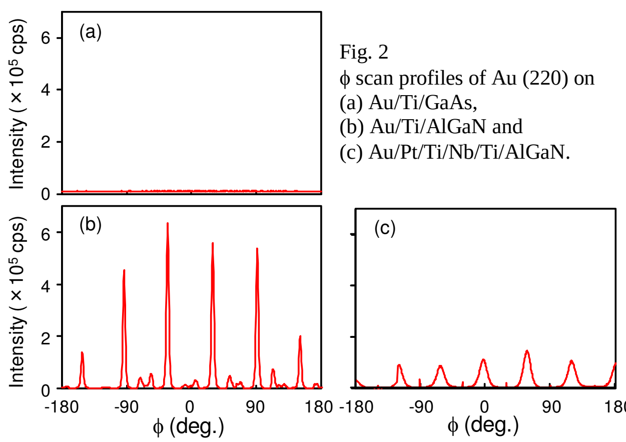

Fig. 2
ϕ scan profiles of Au (220) on
(a) Au/Ti/GaAs,
(b) Au/Ti/AlGaN and
(c) Au/Pt/Ti/Nb/Ti/AlGaN.

To reveal the role of Nb in detail, the SAED patterns of Au/Pt/Ti/Nb/Ti on AlGaN were measured using TEM. Figures 3a to 3c show the SAED patterns of the 1st Ti layer, the Nb layer and the 2nd Ti layer of Au/Pt/Ti/Nb/Ti, respectively. The diffraction patterns of the 1st Ti layer of Au/Pt/Ti/Nb/Ti are assigned to a HCP structure in accordance with those of Au/Ti. Since the SAED pattern of the Nb layer shows spot and ring patterns, it is suggested that a part of the Nb layer is randomly oriented. The out-of-plane epitaxial relations of the 1st Ti and the Nb layers are Nb[110]//Ti[0001]//AlGaN[0001]. The in-plane epitaxial relations of the 1st Ti and the Nb layers are Nb[002] and Nb[$1\bar{1}2$]//Ti[$11\bar{2}0$]//AlGaN[$11\bar{2}0$]. 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 these 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 the 1st Ti layer on AlGaN(0001).

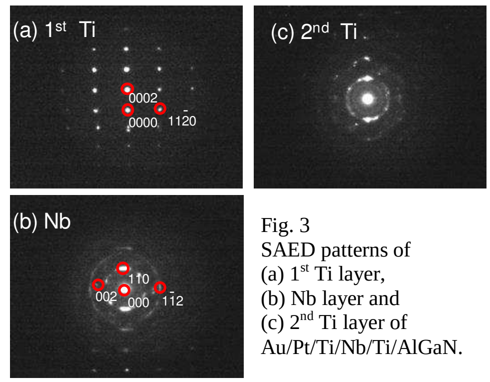

Fig. 3
SAED patterns of
(a) 1st Ti layer,
(b) Nb layer and
(c) 2nd Ti layer of
Au/Pt/Ti/Nb/Ti/AlGaN.

Next, Au films were electroplated on evaporated films. Figure 4 shows that the plated Au films on Au/Ti/GaAs and Au/Pt/Ti/Nb/Ti/AlGaN have uniform surfaces. On the other hand, the surface of the plated Au film on Au/Ti/AlGaN exhibits a peculiar appearance. Thus, the microstructures of films were analyzed using cross-section SEM to investigate the peculiar appearance. The evaporated Au layers of Au/Ti/GaAs and Au/Pt/Ti/Nb/Ti/AlGaN have many grain boundaries as shown in Figs. 4d and 4f. The grain sizes of evaporated Au layers of Au/Ti/GaAs and Au/Pt/Ti/Nb/Ti/AlGaN 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 grain sizes of the evaporated Au layer of Au/Ti/AlGaN are greater than 15 μm as shown in Fig. 4e. The plated Au film has large grains on it and the surface is smooth except for the grain boundary. Therefore, it was 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 crystallinity of evaporated Au films.

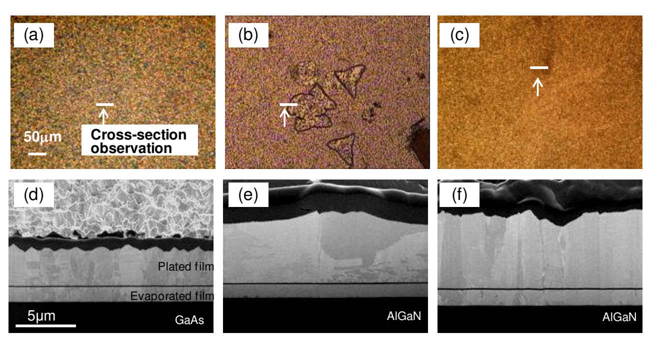

Fig 4 Surface morphologies of (a) Au/Ti/GaAs, (b) Au/Ti/AlGaN and (c) Au/Pt/Ti/Nb/Ti/AlGaN. Cross-section SEM images of (d) Au/Ti/GaAs, (e) Au/Ti/AlGaN and (f) Au/Pt/Ti/Nb/Ti/AlGaN.

The relationship between the grain sizes and the crystallinity of evaporation films is considered. It is suggested that the relationship depends on lattice mismatching with substrates or the underlying metal. In the case of evaporated Ti and Au layers on GaAs, since the crystal nuclei orient randomly, the boundaries of the crystal nuclei become grain boundaries. Therefore, the grain sizes are small. On the other hand, in the case of evaporating Ti and Au layers on AlGaN, the crystal nuclei of Au, whose in-plane orientation angles are mainly 0 and 180 degrees, grow. Since grains which have the same crystal orientation grow together and the boundaries of the crystal nuclei disappear, the grain sizes become large. As a result, the grain sizes are different due to lattice mismatching.

In addition, Fig. 4e shows that the peculiar appearance of Au/Ti/AlGaN corresponds to the grain boundary of the plated Au film. Therefore, it is suggested that since the plated Au film on the Au/Ti/AlGaN forms large grains, the grain boundaries take on their peculiar appearance.

CONCLUSIONS

When Au film is electroplated on a Au/Ti layer which grows epitaxially on AlGaN, a peculiar appearance occurs at the surface to increase its grain size. When an Nb layer is inserted between the Ti layer and GaN in evaporated film, the atomic arrangements of Au/Ti are disturbed and grain sizes of the plated Au film on the evaporated film are smaller. As a result, the surface morphology is uniform like plated Au film on GaAs.

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ACRONYMS

HEMT: high electron mobility transistors
FCC: face-centered cubic
HCP: hexagonal close-packed
BCC: body-centered cubic
XRD: x-ray diffraction
TEM: transmission electron microscope
SEM: scanning electron microscope
SAED: selected area electron diffraction