Crystal growth of AlN on Al/sapphire IDT at the resonance point of nitrogen-ECR plasma

K. Murano [a)], T. Inushima [a)], A. Hasebe [a)], Y. Wakasugi[a)], H. Kondo [a)], Y. Koizumi [a)], T. Shiraishi [a)], V. Yu. Davydov [b)] and S. Ohoya [c)]

[a)]School of Engineering, Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa 259-1292, Japan
[b)]Ioffe Physico-Technical Institute, Russian Academy of Science
26 Polyteckhnicheskaya 194021 St. Petersburg, Russia
[c)]Kanagawa Industrial Technology Research Institute
705 Shimoimaizumi, Ebina, Kanagawa 243-0012, Japan
e-mail:inushima@keyaki.cc.u-tokai.ac.jp

AlN is an attractive material for its high thermal conductivity, wide band gap and lattice constant similar to that of GaN which is now exciting attention in connection with blue light emitting devices. When we consider the device application of AlN for a surface acoustic wave (SAW) filter, a method to grow high quality AlN on metal Al with smooth surface at low temperatures is required in order to obtain strong electro-mechanical coupling between AlN and Al electrode. Hence many reactive deposition methods have been reported, among which reactive sputtering and reactive evaporation methods have been extensively employed. The obtained crystals are, however, poly-crystalline and electrical properties of them have many points to be improved.

We present a novel technique to grow AlN on metal Al heteroepitaxially by the use of high density active nitrogen species, which are generated at the resonance point of nitrogen-ECR plasma, where metal Al is evaporated. The AlN film having the c-axis perpendicular to the (111) plane of Al together with the c-plane of sapphire was obtained at the growth rate of 0.5 m/hr with the substrate temperature lower than 600 °C. The film had the band gap energy of 6.0 eV and kept good Raman selection rules.

Al of 99.999 % purity was used as the evaporation material. The substrates and the Al source crucible were set at the resonance point of the ECR plasma. The crucible was made of Ta and had a Ta cover to protect Al from N_2 plasma. A hole of the diameter of 1mm was made on the cover. The stainless steel sample holder with sapphire substrate was set 3 cm above the crucible. The quality of AlN was sensitive to the back pressure of the chamber and it was necessary to clean the chamber with hydrogen plasma for several hours in order to keep the inside pressure in the order of 10^{-7} Torr.

Figure 1 shows the XRD patterns of the AlN film deposited on IDT (InterDigital Transducer) which has 150 m line and space Al electrodes on sapphire c-plane. Metal Al is deposited onto the sapphire c-plane by high vacuum rf magnetron sputtering method at 450 ºC and its thickness is 400 nm. The evaporated Al is crystallized weakly on the sapphire and it shows (111) reflection. It is seen that strong (002) reflection of hexagonal AlN is observed, from which it is obvious that the c-axis of AlN is perpendicular to the substrate and Al (111) plane. The cross sectional view of SEM image shows that AlN is smoothly grown on sapphire and Al and there is no degradation on Al electrodes.

Fig. 2 shows the Raman spectra of AlN on IDT substrate. The thickness of AlN is almost 1 m. In this experiment, z-axis is chosen to be parallel to the sapphire c-axis. At the X(ZZ)X configuration, where the incident laser light (X) is parallel to the surface of the film, that is, perpendicular to the c-axis, and the polarization of the light is parallel to the c-axis (Z), we observe three phonons at 610, 640 and 890 cm^{-1}. These phonons correspond to A_1(TO), E_2 and E_1(LO), respectively, when we take into account the reported phonon energies of A_1(TO) at 610 cm^{-1}, E_2(high) at 640 cm^{-1} and E_1(LO) at 910 cm^{-1}. At the Z(XX)Z configuration, where the incident light is perpendicular to the surface of the film, we expect A_1 (LO) and E_2(high). These phonons are observed at 640 and 890 cm^{-1}, respectively. These phonon energies are same on the AlN grown on Al. From the consideration of the Raman selection rules and phonon frequencies, it is obvious that AlN grown on sapphire and metal Al keeps good Raman selection rules and has grown on the c-plane of sapphire with its c-axis perpendicular to the surface.

By the use of this method, we fabricated SAW filters having line/space of 150 μm. Obtained SAW filters had the resonance frequency of 11.6 MHz and Q factor of 3,000,000. Resonance frequency gives the SAW velocity of 7000 m/s, which is about 20 % faster than that of bulk AlN. High Q-value and high velocity indicates the generation of Lamb wave in this SAW device.

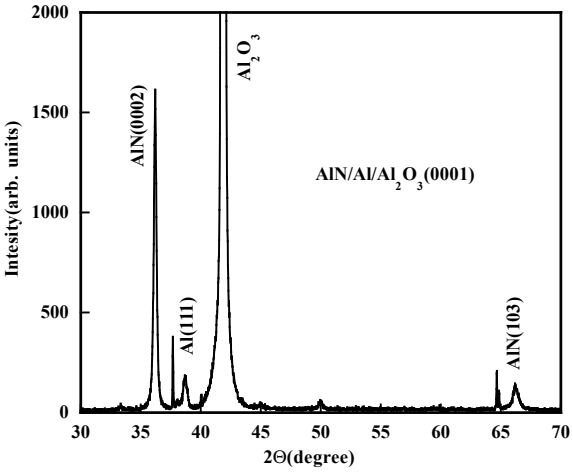

Fig. 1 X-ray diffraction pattern of AlN grown on Al/Al_2O_3IDT structure.

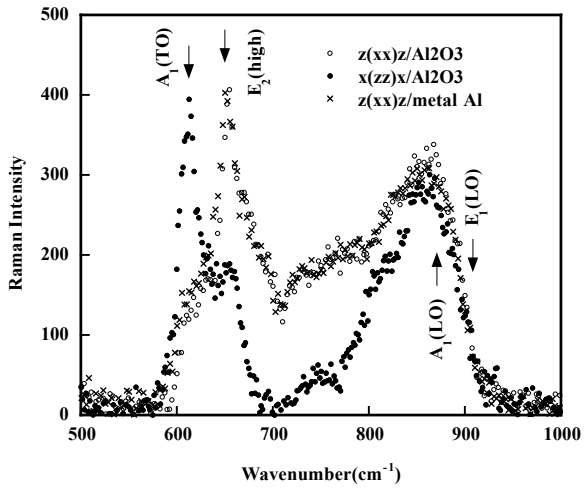

Fig. 2 Raman spectra of AlN grown on Al/sapphire IDT structure