Heavily Si-Doped AlN Electron Field Emitters

Makoto Kasu and Naoki Kobayashi
NTT Basic Research Laboratories
3-1 Morinosato-Wakamiya, Atsugi, 243-0198, Japan
kasu@will.brl.ntt.co.jp

The interest in electron field emitters using nitride semiconductors such as AlN has been increasing because the electron affinity of these materials is expected to be very small. Large electron field emission (FE) from materials with small electron affinity will lead to very thin flat panel displays and microwave power amplifier tubes. However, the reported FE current from AlN is as low as 0.05μA [1]. This is probably because the AlN samples in ref. 1 were not intentionally doped, and, as a result, few electrons were supplied from the substrate to the surface. Therefore, we investigated the effect of Si doping on the electron FE from AlN, and observed large and stable FE current from heavily Si-doped AlN.

Heavily Si-doped 0.2-μm-thick AlN was grown at 1100^{o}C by low-pressure (300 Torr) MOVPE. We chose an n-type (1 x 10^{18} cm^{-3}) 6H-SiC (0001) substrate because it has high electric conductivity and because SiC and AlN have almost the same lattice constants (mismatch: 1%) and thermal expansions along the a axis. The sources were TMG, TMA, NH_3, and SiH_4. The Si dopant density was measured using SIMS. The resistivity of the AlN with the highest Si dopant density (2.5x10^{20} cm^{-3}) was so high that the free electron density could not be measured at room temperature (RT) by Hall measurement. The full width at half maximums of (0002) reflection of the x-ray rocking curve of 0.2-μm-thick nondoped and heavily Si-doped AlN were as low as 91 and 94 arcsec, respectively. Heavily Si-doped AlN surfaces were free from cracks and were very flat; the roughness was less than 50 nm.

Field emission current-voltage (I-V) characteristics were measured using a modified UHV scanning tunneling microscopy (STM) system. The planar sample surface and top surface of the W thumbtack-shaped anode probe were set parallel, enabling us to estimate the emission area, and consequently, the FE current density accurately. The probe-sample distance, an important factor in estimating the electric field strength, was accurately controlled by using an STM circuit. We carefully confirmed that there was no damage on the surface before and after the field emission, and that the I-V data are due to the field emission, not due to discharge.

Figure 1 shows the FE current for different Si-dopant densities (N_{Si}) in AlN. As the Si-dopant density increased, the threshold voltage decreased. This is because Si dopant atoms form an impurity level in the bandgap and the electrons are supplied to the surface through the impurity level. For N_{Si} = 2.5 x 10^{20} cm^{-3}, we obtained low threshold voltage (the threshold electric field) defined at 0.05 nA of 62 V (34 V/μm). Figure 2 shows the FE current for N_{Si} = 2.5 x 10^{20} cm^{-3}. We obtained the maximum FE current (density) of 347 μA (11 mA/cm^2). This maximum current is higher than that previously reported [1].

As shown in Fig. 3, we investigated the stability in the FE current when the applied bias was fixed. There was no feedback system in the circuit. For AlN (N_{Si} = 2.5 x 10^{20} cm^{-3}), the fluctuation (the ratio of the root mean square to the average) was as low as 3%. The observed high stability of AlN indicates little change in the emission site density and a low rate of surface atom evaporation. The FE current stability for AlN is within the value necessary for flat-panel FE display application.

For the flat panel display application, we observed light emission from red, green, blue, and white phosphors excited by the field-emitted electrons from AlN (N_{Si} = 2.5 x 10^{20} cm^{-3}). The widely used P22 red, green, blue or the P15 white phosphors were coated on the top surface of the W anode probe. When the bias, current, and distance were 3.8 kV, 9 μA, about 100 μm, respectively, the phosphor luminance was estimated to be 1200 cd/m^2, which is sufficient for flat panel displays.

1) A. T. Sowers, J. A. Christman, M. D. Bremser, B. L. Ward, R. F. Davis, and R. J. Nemanich, *Appl. Phys. Lett.* **71,** 2289 (1997).

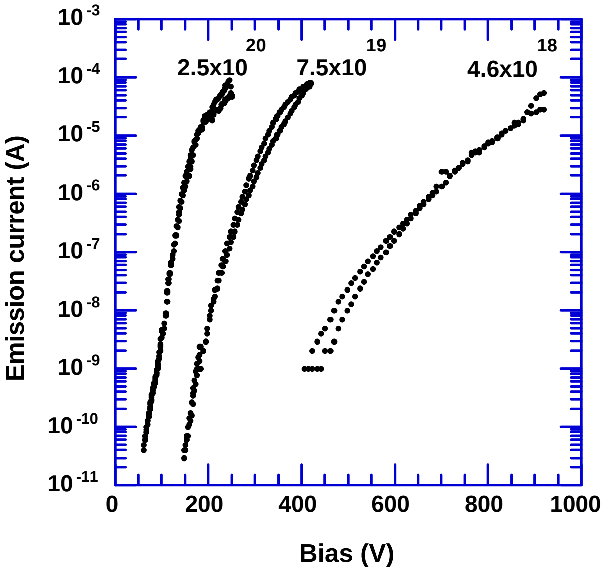

Fig. 1

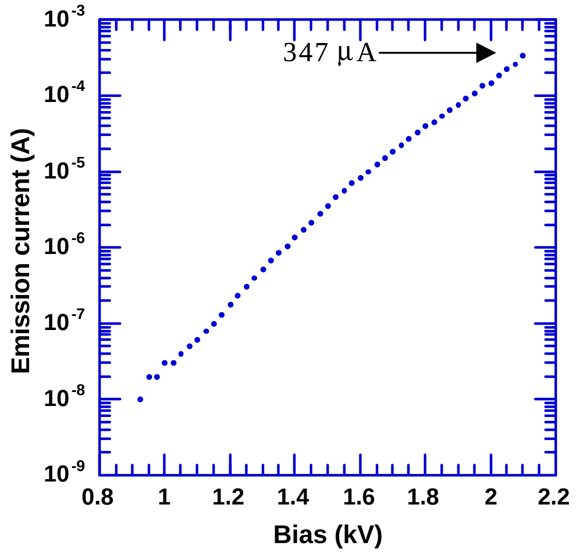

Fig. 2

Fig. 1. Field emission current as a function of the applied bias voltage for AlN with different Si dopant densities (N_{Si}, cm^{-3}). The sample-probe distance was 1.8 μm.

Fig. 2. Field emission current with N_{si}= 2.5x10^{20} cm^{-3} and the sample-probe distance of about 25 μm. The maximum current (density) was 347μA (11 mA/cm^2).

Fig. 3. Stability of field emission current over time for AlN (N_{Si} = 2.5 x 10^{20} cm^{-3}) and Si (n = 5x10^{19} cm^{-3}, the highest value available).

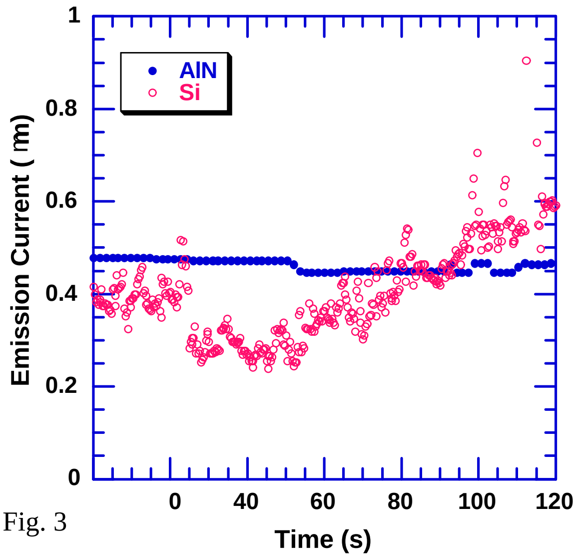

Fig. 3