Si 基版上 GaN デバイスの低コスト化技術

Development of low cost fabrication process for GaN devices on Si substrates

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We have developed a new low temperature crystal growth technique named PSD (pulsed sputtering deposition) for fabrication GaN devices.　With the use of the PSD technique, we have succeeded in growth of high quality thick nitride films on Si (110) substrates and confirmed alleviated thermal stress by reduction in growth temperature. We have also succeeded in fabrication and operation of various nitride devices such as full color RGB LEDs with PSD. These results indicate that the PSD low-temperature growth technique is quite promising for fabrication of low-cost GaN devices on Si substrates.

1. Introduction

It is well known that devices based on group III nitride semiconductors show very high performance, but their applications are quite limited because of the high fabrication cost for their processing by sophisticated methods such as MBE or MOCVD. To solve this problem and fabricate low-cost GaN devices, we have to utilize a highly productive crystal growth technique. We have recently developed a new growth technique named PSD (pulsed sputtering deposition) and found that it allows us to obtain device quality III nitrides even at room temperature [1]. (see Table 1)　PSD has already attracted much attention of industry engineers because its productivity is much higher than that of conventional MOCVD. In this technique, surface migration of the film precursors is enhanced and, therefore, the temperature for epitaxial growth is dramatically reduced. This reduction in growth temperature allows us to utilize various large area low cost substrates. Among various low-cost large area substrates, the use of Si substrates is quite promising because of their high crystalline quality. Si (110) instead of conventional Si (111) is especially attractive as substrates for GaN devices because the use of it allows us to integrate Si MOS devices with GaN based optical and power devices. However, the use of conventional growth techniques of GaN such as MOCVD for Si leads to formation of a high density of cracks due to its high growth temperatures above 1000°C. In this presentation, we will demonstrate successful epitaxial growth of high quality GaN and operation of various GaN based devices on Si (110) substrates by the use of the PSD low temperature growth technique.

2. **Results and Discussion**

Prior to fabrication of devices on Si substrates, we have investigated basic properties of PSD-GaN and its devices prepared on conventional sapphire substrates. High resolution x-ray diffraction measurements have revealed that crystalline quality of nitride films prepared by PSD is comparable with those prepared by MOCVD. Figure 1 shows XRCs for AlN grown at room temperature (RT) on 6H-SiC. One can see that RT AlN exhibits high crystallinity and it survives even after annealing at as high as 1200°C. Room temperature photoluminescence measurements have revealed that PSD-GaN shows strong near-band-edge emission with narrow FWHM values of 30-40 meV. Typical GaN films prepared by PSD is highly resistive but they can be doped into n-type or p-type by introduction of Si or Mg, respectively. Typical electron mobility is 600-700 cm^2/Vsec at carrier concentrations on 10^{16} cm^{-3}. These basic properties are summarized in Table 2. The most striking advantage in the device application of PSD is suppression of phase separation reactions in InGaN, which is crucial for fabrication of long wavelength LEDs and solar cells. In fact, we have successfully fabricated RGB full color LEDs with the use of the PSD low temperature grown InGaN, which are shown in Fig.2. It should be noted that fabrication of full color LEDs with GaN based materials by conventional MOCVD is quite difficult because high growth temperature of MOCVD causes phase separation of high In concentration InGaN. Therefore, this figure makes striking demonstration of advantage in the PSD low temperature growth technique. The intensity ratio of photoluminescence at room temperature to that obtained at low temperatures is as high as 48% even at a wavelength of 720 nm (red). The other promising application for high In concentration InGaN is solar cells. We have fabricated GaN/InGaN/GaN double hetero solar cells with the use of high In concentration InGaN and measured their characteristics under the AM 1.5 100 mW/cm^2. The PSD solar cells show high Vocs which varies with the In concentration. This result indicates this technique is usable for the fabrication of multi-layer IIIV solar cells with high conversion efficiencies. We have obtained a short circuit current, Jsc, of 4.1 mA at an open circuit voltage, Voc, of 1.1 V. This large Jsc can be attributed to the high crystalline perfection of high In concentration InGaN achieved by low temperature PSD growth. We have also fabricated AlGaN/GaN hetero-structure and confirmed existence of two dimensional electron gas (2DEG) at the hetero-interface by CV measurements. With the use of this 2DEG structure, we have fabricated high electron mobility transistors (HEMTs) and confirmed their successful operation. Performance of the PSD HEMTS was comparable with that processed simultaneously by the use of commercially available MOCVD epitaxial wafers.

We have grown group III nitride materials also on Si (110) substrates. The most severe problem with growth of GaN films on Si substrates is formation of a high density of cracks. In fact, it is known that cracking starts at a film thickness of 0.5 μm if we utilize conventional high temperature MOCVD process. We have found that the use of the low temperature PSD process allows us to grow crack-free GaN up to 1.5 μm. We have also found that introduction of thin AlN/GaN super lattice with a total thickness of 80 nm allows us to grow 7 μm thick crack-free GaN. This improvement can be attributed to the reduced thermal stress during cooling down from the growth temperature to room temperature. These results indicate that reduction in growth temperature is inherently important for successful fabrication of GaN devices on Si substrates.

3. Conclusions

With the use of the newly developed PSD technique, we have succeeded in growth of high quality nitride films on Si (110) substrates at low temperatures and confirmed alleviation in thermal stress by the reduction in growth temperature. We have also succeeded in fabrication and operation of various nitride devices such as full color RGB LEDs, solar cells, and HEMTs with PSD. These results indicate that reduction in growth temperature by the use of the present PSD technique is quite attractive for successful fabrication of GaN devices on Si (110) substrates.

Acknowledgments

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References

[1] K. Sato *et al.*, Appl. Phys. Express **2** 011003 (2009).

Table 1 Summary of growth techniques for GaN

	MOCVD	rf-MBE	PSD
Maximum growth rate	10 μm/hr	1 μm/hr	10 μm/hr
Growth temperature	1000-1200 °C	700-800 °C	0-900 °C
Cost for apparatus	High	High	Low
Substrate scale-up	Difficult	Difficult	Easy
Toxic gas	Necessary	Unnecessary	Unnecessary
Fabricated devices	LEDs, LDs, HEMTs, Solar Cells, *etc.*	LEDs, LDs, HEMTs, Solar Cells, *etc.*	LEDs, HEMTs, Solar Cells, *etc.*

Table 2 Typical properties of GaN prepared by PSD

Electron mobility	**600-700 cm^2/Vs (at carrier concentrations on $10^{16}/cm^3$)**
Hole mobility	**5–15 cm^2/Vs (at carrier concentrations on $10^{17}/cm^3$)**
FWHM of room temperature PL	**30–40 meV**

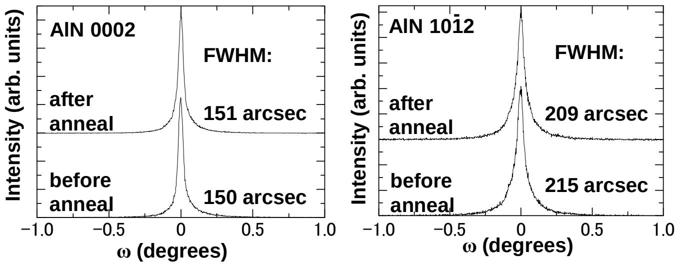

Fig. 1 XRCs for PSD-AlN grown at room temperature on 6H-SiC before and after annealing at 1200°C

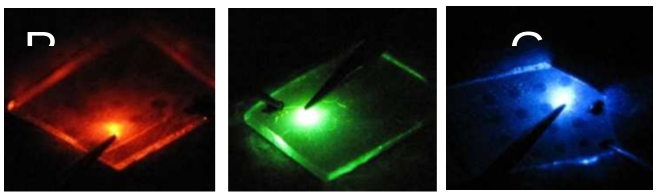

Fig.2 RGB LEDs fabricated with PSD on conventional substrates