Observation of Point Contact Visible Luminescence from Ga-Doped ZnO Layers

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We report the point contact visible luminescence from Ga-doped ZnO layers. The Ga-doped ZnO layers were grown by the thermal oxidation of ZnS substrates with gallium in the air. The injected light emission was observed around the point-contact surface of ZnO layers when a forward DC voltage in the range of 2.5-9.8 V was applied (point contact was positive). Typically, we illustrated the luminescent spectrum for 6.7 V which showed a wide emission band centering at 680 nm.

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I. INTRODUCTION

It is well known that the concentration of hole-electron pairs can be increased above the equilibrium value by optical excitation or injection of minority carriers at a p - n junction or at a metal contact. The point contact luminescence of semiconductors, such as SiC [1], Ge [2] and diamond [3], has been reported previously. The nature of the contact to the semiconductor determines whether there occurs the well-known injection of minority carriers when forward voltage is applied. However, the minority carriers are generally created by minority carrier injection under strong forward-bias conditions [4]. Therefore, to obtain the injected luminescence under low voltage excitation is expected.

As a simple technology of direct conversion of electric energy into visible light, electroluminescence (EL) can be performed easily in industrial application. With a wide direct band-gap of 3.37 eV and a large exciton binding energy of 60 meV at room temperature, ZnO is recognized as one of the promising semiconductors for optoelectronic device applications [5]. To meet the challenges of light emitting diode and flat panel display, many research groups have been focusing on the electroluminescence of ZnO with a p - n junction [6–9]. However, the difficulty in synthesis of high efficient and stable p -type ZnO or growth of heterogeneous semiconductors with small interfacial lattice mismatch restricts the fabrication of ZnO-based LED with homogeneous or heterogeneous p - n junctions [9–12]. Therefore, in recent years, several research groups focused on the low voltage exciting EL of ZnO nanowires, nanorods and microwires with metal-semiconductor (MS) junctions [13–15]. In this paper, we

report the point contact luminescence of Ga-doped ZnO layers by excitation of low voltage at room temperature.

II. EXPERIMENTAL

The Ga-doped ZnO layers were grown by the thermal oxidation of ZnS substrates with molten gallium in the air. The oxidation temperature and time are in the range of 700-900°C and 1-24 h, respectively. The experimental procedure was described in detail previously [16]. The doping of Ga in ZnO was confirmed by XPS [17].

To perform the point contact luminescence of Ga-doped ZnO layer, an Au film with a small area was sputtered onto the ZnO layer, while a steel needle probe was directly touched to the surface of the ZnO layer. When a DC voltage ranging from 2.5 to 9.8 V (point contact is positive) was applied, the light emission could be observed around the contact point. In addition, the brightness of the emitted light increased with the current. However, when the current direction was reversed, the light emission disappeared. N -type of the Ga-doped ZnO layers was confirmed by hot-point probe measurement, which reveals the minority carrier injection under forward voltage.

III. RESULTS AND DISCUSSION

To evaluate the metal/ n -ZnO point contact, two probes touched the surface of Ga-doped ZnO layer, and the current-voltage characteristics were traced at room temperature by an oscilloscope. As shown in Fig. 1, the I-V curve shows a nonlinear shape, which indicates the formation of Schottky contact between the probe and n -ZnO layer. Due to the small radius of probe tip, the diffusion of injected carriers at point contact is much better

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FIG. 1. Room temperature current-voltage characteristics between two probes and Ga-doped ZnO layer.

FIG. 2. Luminescent spectrum of Ga-doped ZnO layer measured at room temperature by feeding a forward direct current of 532 mA at 7.6 V. The image of the corresponding emitted light was taken by a camera.

than at surface contact, which leads to the high-efficiency injection. Thus, the minority carriers (holes) are easily

injected into *n*-ZnO under forward voltage by tunneling through the surface potential barrier [4]. Therefore, it is considered that the light emission originating from the ZnO layer was due to the recombination of the injected minority carriers (holes) with the *n*-type majority carriers (electrons) at the contact point. On the other hand, it should be mentioned that no light emission was observed from undoped ZnO (namely grown without gallium), even if high voltage was applied. It may suggest the key role of gallium impurity in the injected light emission from ZnO layers.

To collect the luminescent spectrum by a spectrophotometer, a large injection was applied at 7.6 V and 532 mA. As shown in Fig. 2, the spectrum shows a wide visible emission band at 680 nm corresponding to the observed emission light. The upward spectrum to infrared emission band indicates that heat was generated which could be owing to lattice vibration. The weak UV emission band could be ignored here. In addition, the luminescent spectrum is quite different from the photoluminescence (PL) spectra [16–18], which could be owing to their different excitation mode. For photoluminescence, electrons are excited to conduction band from valance band by short wavelength laser. In the case of the light emission, electrons are injected into the elevated energy states of the ZnO crystals. Meanwhile, the different excitation energy should also be responsible for the changed luminescence. The similar phenomena were also reported [19], which suggest the easy emission with long wavelength in EL spectra than in PL spectra.

IV. CONCLUSION

In summary, the point contact visible luminescence was observed from the Ga-doped ZnO layers grown by the thermal oxidation of ZnS substrates with gallium. The forward DC voltage could range from 2.5 to 9.8 V. Typically, the light emission observed at 6.7 V showed a wide emission band centering at 680 nm.

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