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Electroluminescence from CVD-grown single-walled carbon nanotube

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1. Introduction

Single-walled carbon nanotubes (SWNTs) are attractive materials for the electronic and optoelectronic nanodevices because of their unique properties. Since it is comparatively easy to contact the electrode directly with lithography, SWNT is a leading material for nanoelectronics. Moreover, since SWNTs emit light in a near-infrared region, it is expected to apply SWNT to a light emitting device in nano-meter size. Recently, some studies about the electroluminescence (EL) from an individual SWNT were reported [1-3]. Some emission mechanism involving the recombination of electrons and holes injected from the electrodes [1], the impact excitation of hot carriers [2] and thermal emission [3] were proposed. Quite recently, EL from the SWNT network was also reported [4].

In this paper, we fabricate individual SWNT-FETs and SWNT film-FETs, in which SWNTs are grown by chemical vapor deposition (CVD) method, and measure the electrical and optical properties. We observe the EL from these devices and investigate the emission mechanisms. In the individual SWNT-FETs, the EL with high emission energy was observed as compared with the previous reports.

2. Experimental Procedures

Figure 1(a) shows schematic picture of a SWNT-FET device. A p++ Si wafer with thermally oxidized SiO_2 layer of 500 nm thickness was used as the substrate. SWNTs were grown on a substrate by CVD using ethanol and Co catalyst at 850 ℃. Palladium (Pd) source and drain contacts were fabricated by means of electron beam lithography and lift-off process. We fabricated two types of FETs. One is the FETs using an individual SWNT (SWNT-FETs) and the other is the FETs using SWNT film (SWNT film-FETs). Figure 1 (b) shows the scanning electron microscope (SEM) image of the fabricated SWNT-FET. In this device, a few SWNTs are contacted to the source and drain electrodes.

The EL from the SWNT-FET and SWNT film-FETs was measured under applying DC drain-source voltage (V_{ds}) in vacuum. The EL spectra were detected by a spectrometer with InGaAs photodiode array through a microscope objective. By performing electric measurement and optical measurement simultaneously, the relations between electric properties and luminescence spectra were investigated. A back gate voltage (V_g) was applied through the substrate.

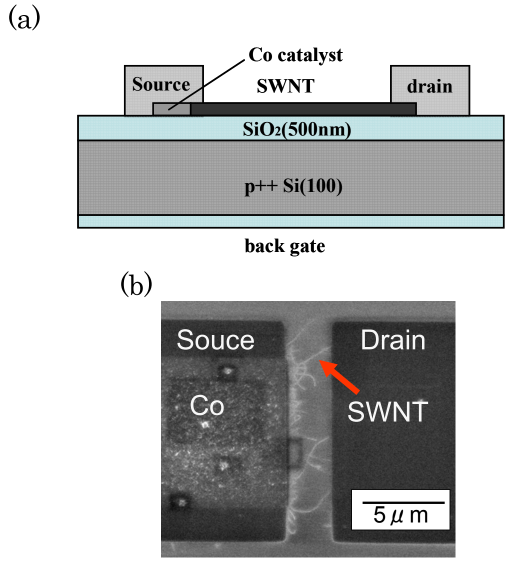

Fig. 1. (a) Schematic picture of a SWNT-FET device. (b) SEM image of the device.

3. Results and Discussion

From the V_{dg} dependence of the current (I_{ds}), SWNT-FET and SWNT film-FET devices showed the unipolar p-type characteristics under applying low V_{ds}. This is due to the high work function of Pd electrode metal. i.e the Schottky barrier (SB) height of holes is low, and holes are injected to SWNT. Current is depleted by applying the positive V_g. It means that SWNT which contacted the electrode is one semiconductor SWNT. However, by applying high V_{ds} to SWNT-FET, it changed to the ambipolar characteristics. These ambipolar characteristics remain after removing high V_{ds}. Similar conversion from unipolar characteristics to ambipolar is previously reported; this is due to the formation of strong chemical bonds between the electrode metal and SWNT [5].

In order to investigate electrical and optical properties of SWNT, we simultaneously measured EL and electric properties of SWNT-FET. In the SWNT-FET, the current flows through a few SWNTs that contact to the electrodes; therefore, the relation between the electric and optical properties can be discussed. Figure 2(a) shows the EL spectrum at V_{ds} = 0-15 V. Single peak at 1.15 eV is clearly observed, independent of V_{ds}, and the peak intensities are monotonically increased with increasing V_{ds}. Since satellite peaks are not observed, it turns out that observed EL spectrum is ob-

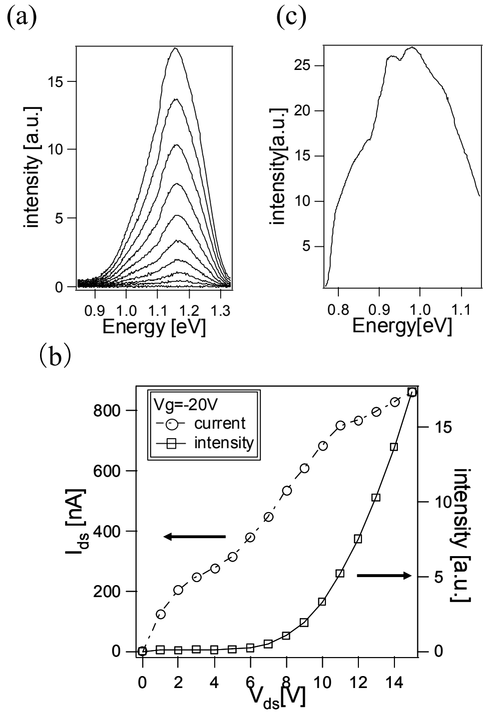

Fig. 2. (a) EL spectra for SWNT-FET at V_{ds} = 0-15 V and V_g = 0 V. (b) V_{ds} dependence of the EL intensity and drain current (I_{ds}). (c) EL spectrum for SWNT film-FET at V_{ds} = 15 V and V_g = 0 V.

tained from an individual SWNT. Since the emission spectrum resembled the previous report from the viewpoint of full width at half maximum (FWHM) [1-3] in addition to the peak shift independent of V_{ds}, the luminescence should not be attributed to the blackbody radiation.

Figure 2(b) shows the V_{ds} dependence of the EL intensity and drain current (I_{ds}). The V_{ds} onset of clearly detectable EL emission is observed at V_{ds} ~6V, and the EL intensity rapidly increases above 6V. On the other hand, I_{ds} almost linearly increases in whole range of V_{ds}.

Gate voltage (V_g) dependences of the I_{ds} and EL intensity at V_{ds} = 15 V are shown in Fig. 3. I_{ds} shows the ambipolar characteristics, which takes a minimum value at V_g = -9 V (n-type region is emphasized by the band bending due to high V_{ds} compared with the date at low bias). However, EL shows maximum intensity around this gate voltage. These results indicate that the EL emission is dominated by the minority carriers, whose number is maximum around the minimum in I_{ds}. That is, the EL emission is caused by the recombination of electrons and holes injected from the source and drain electrodes, and the emission intensity is proportional to the minority carrier density. As shown in Fig. 2(b), this device has a threshold voltage for emission, but the current increases in whole voltage range. This result conform to the emission mechanism dominated by the minority carriers: emission intensity and current are dominated by minority and majority carriers, respectively.

Another mechanism of the EL emission involving the impact excitation of carriers is proposed in Ref. 2. In this mechanism, the emission intensity is proportional to the

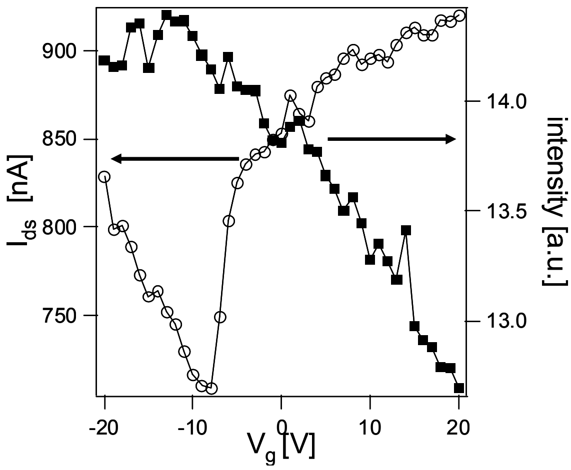

Fig. 3. V_g dependences of the I_{ds} and EL intensity at V_{ds} = 15 V.

carrier impact excitation rate. i.e. emission intensity would increase with increasing I_{ds}; therefore, this mechanism is improbable to be responsible for the observed result of Fig.3. The thermal emission mechanism [3] is also inconsistent with the relation between emission intensity and I_{ds} in Fig.3. The emission intensity would increase with increasing total power in this mechanism. Additionally, it was previously reported that the EL involving the thermal emission shows the negative differential conductance in the range of EL detection [3]. However, our device shows the no negative differential conductance in the EL emission range of Fig. 2(b); therefore, it is improbably that the obtained emission is due to the thermal emission mechanism.

Moreover, the observed emission energy (~1.15eV) is higher than that of the previous reports [1-4]. It is not certain why high energy luminescence is obtained from our devices, but it might be affected by change of interface between the electrode and SWNT due to applying the high voltage.

EL is also observed for the SWNT film-FET as shown in Fig. 2(c). Since a large number of SWNT exists in SWNT film-FET, the broad EL spectrum (~300meV) due to the superposition of the many SWNT peaks is observed as compared with that of SWNT-FET (~200meV).

4. Conclusion

EL is obtained from the fabricated SWNT-FET and SWNT film-FET, in which SWNTs are grown by chemical vapor deposition (CVD) method . The emission is explained by the mechanism dominated by the minority carriers.

References

[1]J.A.Misewich et al., Science, **300**, 785(2003)
[2]J.Chen et al, Science,**310**,1171(2005)
[3]D.Mann et al, Naturetechnology, **2**, 33(2007)
[4]E.Adam et al, Nano Letter, As soon as publishable
[5]H.Oh et al, Applied Physics Letters,**88**,103503(2006)