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Improvement of Breakdown Field of Carbon Nanotubes by a Ti-Capping Layer on Catalyst Nanopaticles

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Introduction

Carbon nanotubes have attracted great attention because of its outstanding physical properties and potential applications since its first observation in 1991 [1]. One of the most promising applications is the field emission device for flat panel display. For FED (Field Emission Display) application, the reliability problems are very essential. However, the breakdown field, which may result from the poor adhesion between carbon nanotubes and substrate, at high voltage causes permanent damages and limits the emission current density from the carbon nanotubes [2][3][4]. In our research, we have improved the breakdown field of carbon nanotubes-based emitters by depositing a 5 nm (Ti) thin capping layer on catalyst nanoparticles. Our samples were measured by Keithley 237 at 10^{-6} torr. Compare with the conventional devices, a higher breakdown field and higher emission current density were observed.

Experiments

A 50nm Ti was deposited by E-gun evaporation on a (100) N-type low resistance (1-10 Ω) silicon wafer as a buffer layer. Then we deposit 5nm iron by E-Gun evaporation as the catalyst metal. After that, some samples were loaded into a thermal-CVD chamber for hydrogen pretreatment (H_2: 500 sccm) at 700 °C for 5 min then grew carbon nanotubes in C_2H_4 (5 sccm)/N_2 (500 sccm) mixed gases at 700 °C for 10 min. Others were unloaded from the chamber after hydrogen pretreatment for 5 min and deposited a 5 nm thin Ti layer as a capping layer. After capping procedure, these samples were loaded into the thermal-CVD again to form carbon nanotubes in C_2H_4 (5 sccm)/N_2 (500 sccm) mixed gases at 700 °C for 10 min. The processes are shown in Fig. 1.

Results and Discussion

We surmise that the Ti atoms in thin capping layer moved at 700 °C and accumulated near the boundary between nanoparticle and substrate (see Fig. 3). The melting point of Ti is 1668 °C. However, the capping layer is only 5 nm and the Ti atoms in an ultra-thin film can move easier than in bulk material. The morphologies of two different conditions (Fig .1(f) and Fig. 1(h)) are shown by SEM in Fig. 2. From the images of SEM, we can find that the density of carbon nanotubes is much lower with thin Ti capping layer after hydrogen pretreatment. It might result from that parts of carbon nanotubes were still sealed in Ti capping layer.

Our samples were measured by Keithley 237 at 10^{-6} torr. The emission current density vs. electric field is shown in figure 4. From Fig. 4, we can find that carbon nanotubes with thin Ti capping layer have much higher breakdown field. The breakdown field of conventional device is 4.7 V/um. However, the carbon nanotubes with thin Ti capping layer seem not breakdown under the same measurement conditions. This phenomenon may due to the improvement of adhesion between nanoparticles and substrate by the thin Ti capping layer deposited on the catalyst nanoparticles.

Summary and conclusions

With thin Ti capping layer (5 nm) after hydrogen pretreatment, we can improve breakdown field. By means of capping layer, we can improve the adhesion between nanoparticles and substrates and avoid permanent damages during high electric field operation. It can increase the breakdown field of carbon nanotubes-based emitters.

Acknowledgements

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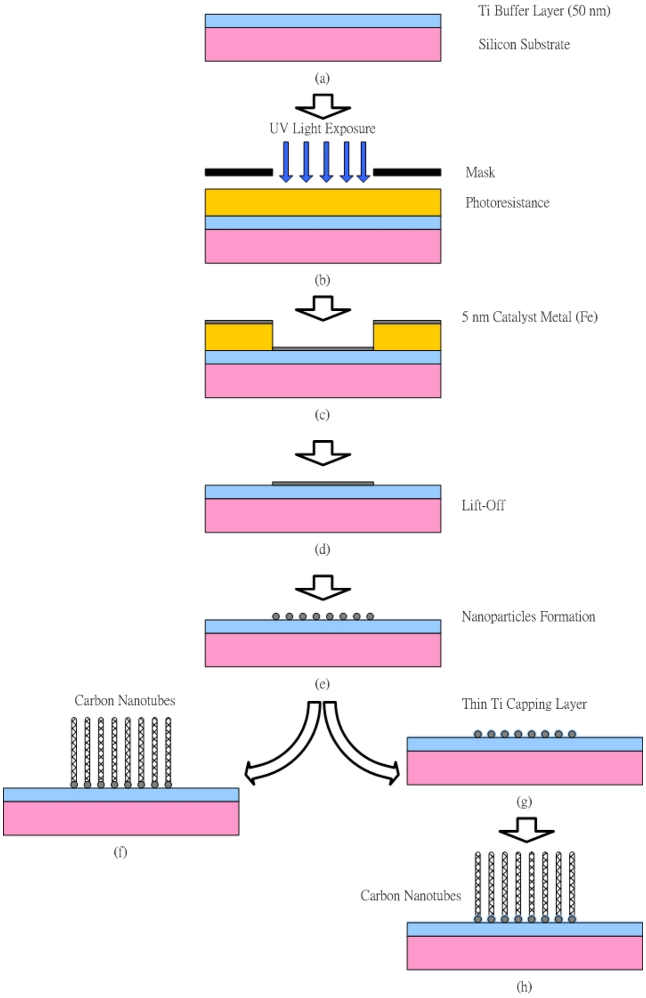
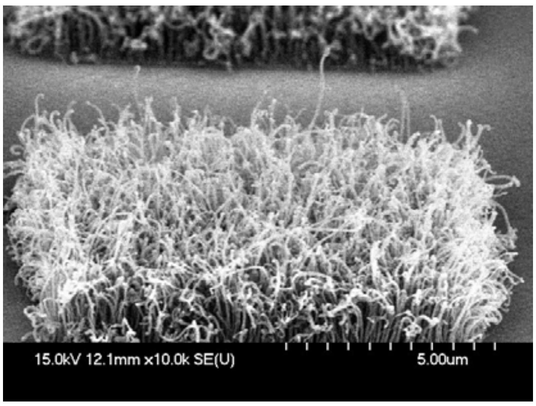
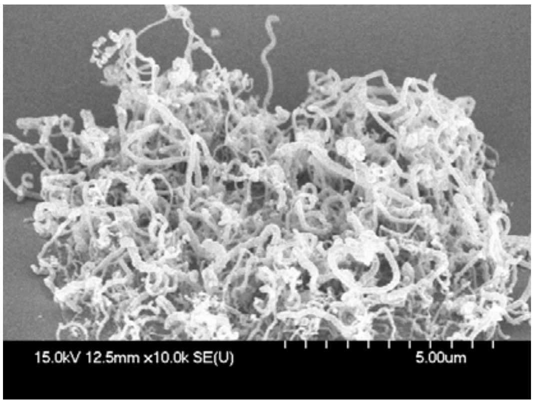


Fig.1 Fabrication procedure of carbon nanotubes (a) Ti buffer layer 50 nm on silicon substrate (b) pattern by UV light (c) deposit catalyst metal 5 nm on Ti buffer layer (d) remove photo-resistance (e) pretreatment in H_2 at 700 °C for 5 min to form nanoparticles (f) grow carbon nanotubes in C_2H_4/ N_2 mixed gases at 700 °C for 10 min (g) deposit a thin Ti capping layer (3 nm) on catalyst nanoparticles (h) grow carbon nanotubes in C_2H_4/ N_2 mixed gases at 700 °C for 10 min



(a)



(b)

Fig.2 (a) SEM of carbon nanotubes without Ti capping layer (b) SEM of carbon nanotubes with Ti capping layer

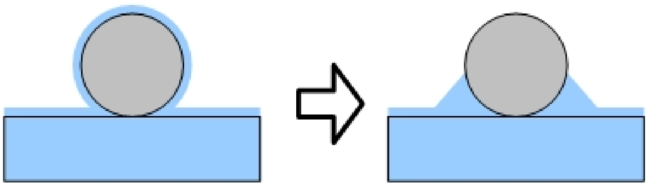


Fig. 3 The Ti atoms of thin capping layer might move during carbon nanotubes growth at 700 °C and accumulate near the boundary between the nanoparticle and substrate.

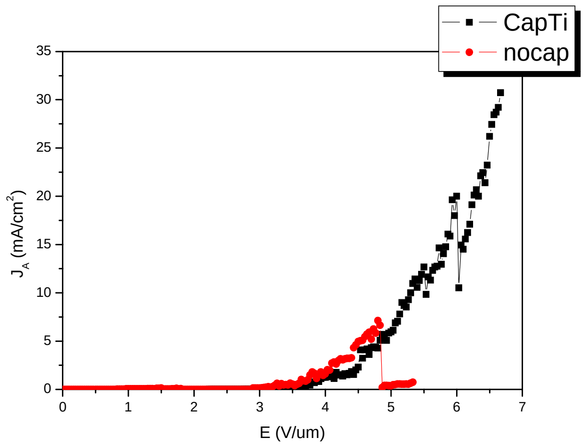


Fig. 4 The current density vs. electric field of carbon nanotubes with Ti capping layer and without Ti capping layer.