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Application of diamond film to cold cathode fluorescent lamps for LCD backlighting

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Abstract

A cold cathode fluorescent lamp (CCFL) is a gas discharge light source widely used for liquid crystal display (LCD) backlighting. We proposed applying diamond as a new cathode material to reduce the power consumption of the CCFL. In this work, we show stable and low (less than 50% of metal) cathode-fall voltage for a glass discharge tube.

Keywords: Cold cathode fluorescent lamp; Discharge; Cathode-fall voltage; Ion-induced secondary electron yield; Diamond; NEA

1. Introduction

A cold cathode fluorescent lamp (CCFL) is a gas discharge light source widely used for liquid crystal display (LCD) backlighting. In regard to the CCFL, there is an urgent need to lower the power consumption while keeping long lifetime. In order to satisfy this requirement, we proposed applying diamond as a new cold cathode material for gas discharge [1]. Almost 30% of the CCFL input power is consumed as the cathode-fall voltage V_c, which is a large voltage drop in front of the cathode, and known to be dependent on ion-induced secondary electron yield γ of the cathode material. The first advantage of diamond as a cold cathode material is large γ, which results from negative electron affinity (NEA). Indeed, it was reported that hydrogen-terminated un-doped polycrystalline diamond films have large γ-value of up to 0.5, which was deduced from AC breakdown voltage measurements [2]. The second advantage is extremely low sputtering yield by ion bombardment, which is expected to extend the lifetime of the cathodes.

We have already reported that hydrogen-terminated boron (B)-doped polycrystalline diamond films show V_c of 70 V, which is about one-half of that of conventional metal cathodes [3]. The films were grown on 14-mm-square Mo plates by microwave plasma chemical vapor deposition (CVD), and the discharge characteristics were measured using open glass cell in

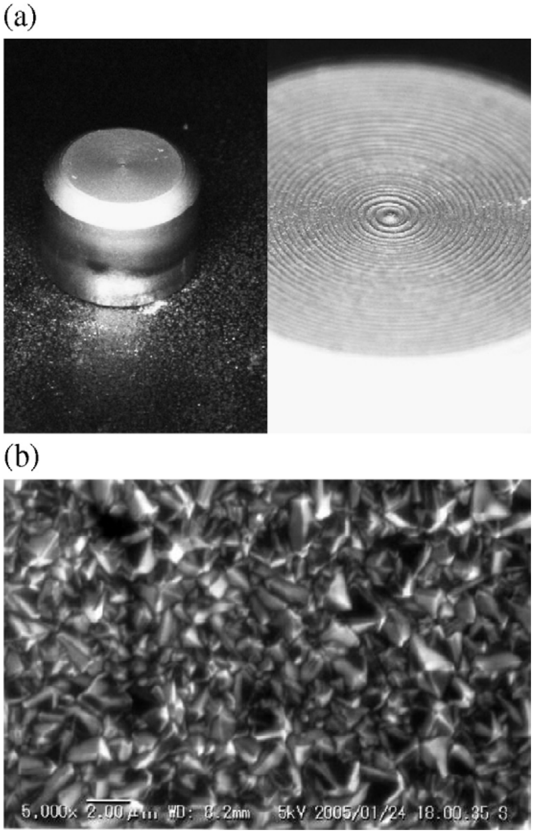

Fig. 1. A diamond cathode: (a) micrographs of a Mo rod with diameter of 4 mm coated with diamond film and (b) a SEM photograph of diamond film by CVD.

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Table 1
Growth conditions for CVD diamond on Mo rod

Pressure (Torr)	50
Source gas	Acetone
Dopant source	Trimethyl borate $B(OCH_3)_3$
Microwave power (W)	1500
Temperature (°C)	850–950
Film thickness (μm)	4
B concentration (cm^{-3})	10^{20}

a gas-filled chamber [2]. After that, we fabricated the first prototype glass discharge tube using rod-shaped diamond cathodes. However, it did not show low V_c. Therefore, the rod-shaped diamond cathode itself was re-examined by means of measurements in the chamber.

In this work, we show stable and low V_c of 70 V for a glass discharge tube using the diamond cathode. Also, we present novel findings concerning the hydrogen termination method for the discharge tube.

2. Diamond cathode and experimental set-up

Fig. 1 shows a rod-shaped diamond cathode. B-doped polycrystalline diamond films were grown on Mo rods with diameter of 4 mm by microwave plasma CVD. Table 1 shows growth conditions. Fig. 2 shows experimental set-up for discharge measurements. Two cathodes were set with a given gap length d in the vacuum chamber. After evacuation to about 5×10^{-5} Pa, Ar gas was introduced. Next, sinusoidal high voltage V was applied to the cathodes and current–voltage waveforms were measured while varying gas pressure p. A resistor R was inserted to sense the discharge current and protect destructive arcing.

3. Results

Fig. 3 shows discharge waveforms of the diamond cathodes in the case of two different surface treatments. When voltage across the cathodes V_L reaches a value of V_f, discharge starts and discharge current I_L flows. After that, V_L remains a constant value of V_c, regardless of discharge current. V_f is the firing voltage and V_c is the above-mentioned cathode-fall voltage. Hydrogen plasma treated diamond (a) shows V_c of 70 V, however, after acid dipping (b), V_c is degraded to 100 V. This is consistent with electron affinity change due to the same treatment. From this result, it was supposed that loss of hydrogen termination during the tube fabrication process was the reason for high V_c of the first prototype.

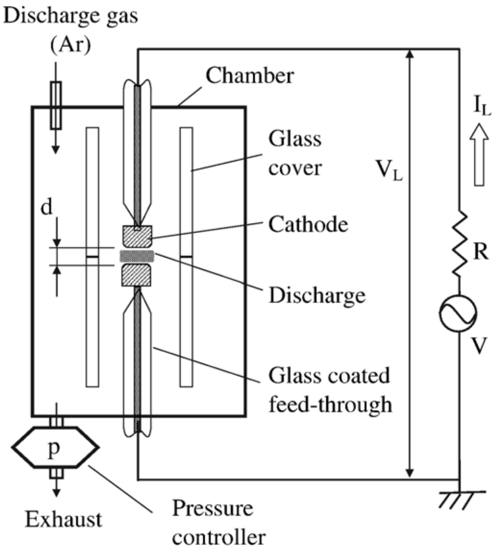

Fig. 2. Experimental set-up for discharge measurements.

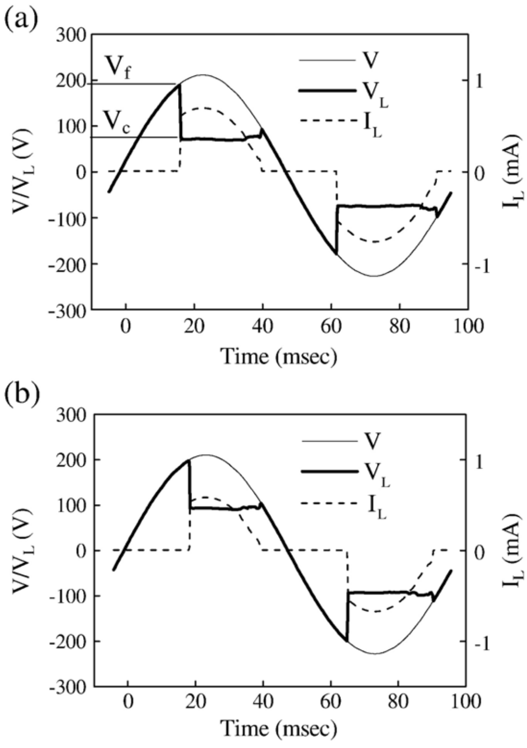

Fig. 3. Discharge waveforms of the diamond cathodes: (a) hydrogen plasma treated and (b) oxidized by acid dipping (p=20 Torr, d=2 mm). The values of V_c for (a) and (b) are about 70 V and 100 V, respectively.

To take measures to meet the situation, we explored a method to recover and maintain low V_c of the diamond cathodes after the acid treatment or the tube fabrication process. It was found that

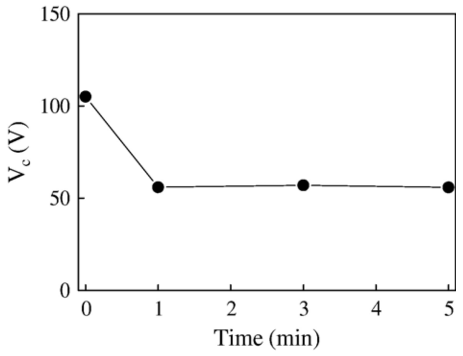

Fig. 4. Reduction of V_c by adding a small amount of hydrogen to the discharge gas (p=10 Torr, d=4 mm, H_2/Ar=0.2%). Before measurement, the cathodes were dipped in acid.