An a-D film for flat panel displays prepared by FAD

Xianghuai Liu and Dongsheng Mao

Ion beam laboratory, Shanghai Institute of Metallurgy, Chinese Academy of Sciences, Shanghai 200050, P.R.China

ABSTRACT

Details are given of an study of the characteristics of field-induced electron emission from hydrogen-free high sp^3 content (>90 %) amorphous diamond (a-D) film deposited on heavily doped (ρ<0.01 Ω·cm) n-type monocrystalline Si (111) substrate. It is demonstrated that a-D film has excellent electron field emission properties. Emission current can reach 0.9 μA at applied field as low as 1 V/μm, and emission current density can be obtained about several mA/cm^2. The emission current is stable when the beginning current is at 50 μA within 72 hours. Uniform fluorescence display of electron emission from whole face of the a-D film under the electric field of 10~12 V/μm was also observed. It can be considered that the contribution of excellent electron emission property results from its smooth, uniform, amorphous surface and high sp^3 content of the a-D films.

1 Introduction

Field emission displays (FED) with emission current density as high as 10~1000 A/cm^2 have been achieved in metal-tip emitters and silicon-tip arrays, respectively. They have great potential for applications in flat panel displays. However, the electric field needed for occuring the field emission of these devices is rather high. Moreover, their performance degrades rapidly due to thermal effect. With the rapid development of diamond film technology, there has been a growing interest in its potential application to the fabrication of cold cathode electron sources for flat panel displays because of their low or even negative electron affinity (NEA) and outstanding chemical inertness[1]. Indeed, there were several studies of the field emission properties of thin film diamond structures[2-5]. Observations of electron emission from chemical vapor

depositied (CVD) diamond under relatively low electric fields of 3-40 V/μm were reported[6-8]. Fabrication of diamond field emitter arrays has also been attempted[9], and a diode-structured prototype field emission display based on a diamond-like carbon cathode has been demonstrated[10]. But previous results showed that the electron emission from diamond films are not stable and reliable, especially it is not uniform[2-5]. Photoemission images showed that the emission area was small, only a small number of emission points distributed on the fluorescent screen, and the brightness of the concrete points was quite different. Because several kinds of crystal facets exist on the surface of CVD diamond films, which have different barrier potential, resulting in the nonuniformity of the field emission current density.

Hydrogen-free amorphous carbon thin films with diamond-like behavior are now studied extensively[12-15]. Compared to hydrogenated carbon films, they have lower electron affinity and contributes to their emission properties[11,16,17]. Their surfaces are more smooth and uniform. Filtered arc deposition (FAD) is an excellent method to deposit hydrogen-free amorphous carbon films. Because of their high sp^3 content(>80%), they are also called amorphous diamond (a-D). There are only several laboratories used this method to deposit hydrogen-free a-D films[18].

In this paper, field electron emission properties of FAD hydrogen-free high sp^3 content a-D films are studied.

2 Experiment

The diamond films are prepared using FAD technology. The details of this FAD system have been reported previously[21]. The films are deposited onto heavily doped n-type monocrystalline Si (111) substrates ($\rho<0.01\Omega$ cm) at -200V bias voltage. The substrate holder is held at room temperature. The substrates are cleaned in situ by an ion beam sputtering at 0.6KeV for about 60 seconds prior to deposition. The use of magnetic field can filter macroparticles and neutral grains. The filtered beam is nearly 100% ionized and horizontally/vertically scanned in the deposition process so as to keep uniformity of the films. The deposition rate is about 5A/sec. Deposition time is controlled about 10-15minutes.

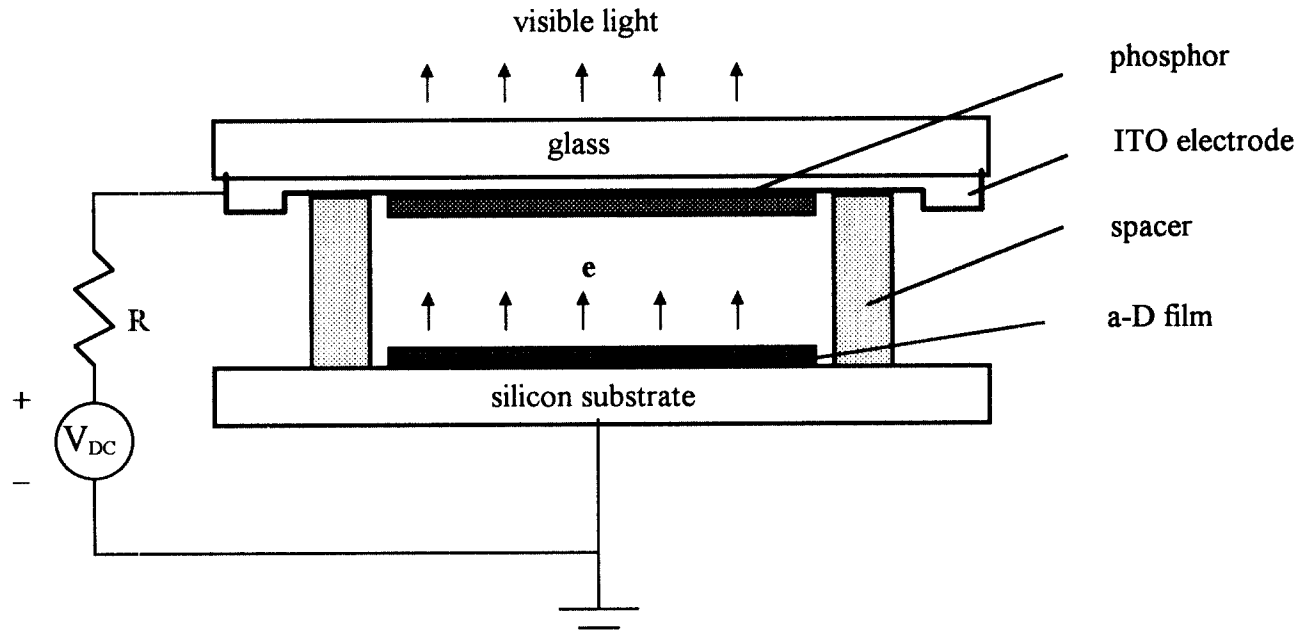
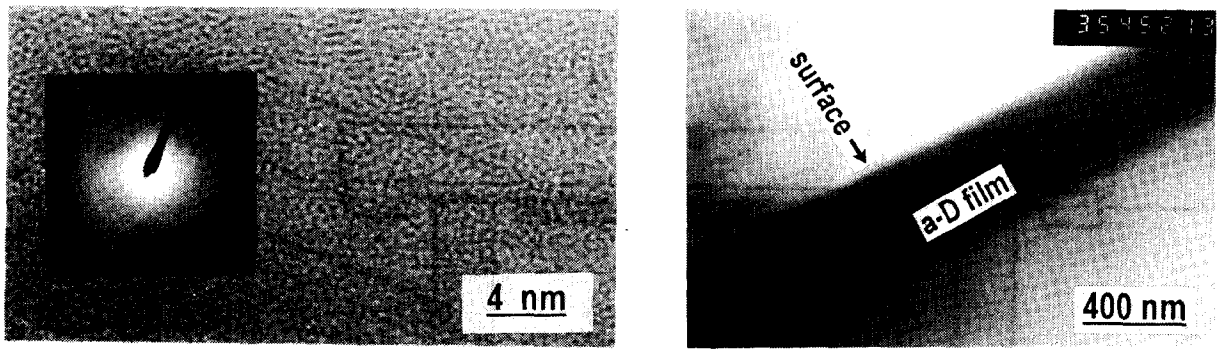


Fig 1 Schematic diagram of field emission imaging configuration

Field electron emission properties of a-D film based on a diode structure are studied (see fig 1). The anode consists of a ZnO:Zn-phosphor + ITO coated glass plate whereas the a-D film acts as a cathode. The two plates are parallelly separated by spacers formed by 100μm thick insulating Teflon. Under certain electric field, electrons run off from the surface of the a-D film and bombard phosphor with their kinetic energy, and result in the luminescence of the phosphor-coated screen.

3 Results and discussion

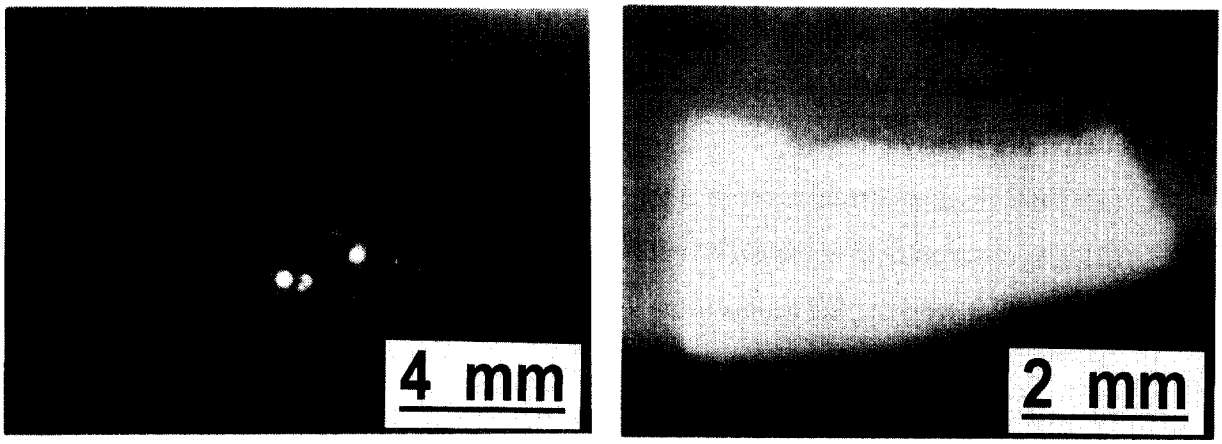
By FAD system, hydrogen-free high sp^3 content (>90 %) a-D film is obtained. Its density (3.35 g/cm^3) is very close to that of natural diamond. Fig 2 are transmission electron microscopy (TEM) images of a-D film. The high resolution TEM image shows that the grain is nanometer scale. The electron diffraction patter (inset) displays a faint halo-ring, indicating that the film is amorphous. Fig 2(b) shows that the thickness of the film is about 400nm, and the surface is very smooth. The characteristic is quite different from that of polycrystalline diamond prepared by CVD method.



(a) Showing the film is amorphous (b) showing the thickness of the film is about 400nm

Fig 2 TEM images of amorphous diamond film

Different photoemission images can be observed with the increasing value of the voltage. Several emission points are displayed on the phosphor screen in the beginning. An increase on anode voltage cause an increase on the number of emission points and the points become brighter, simultaneously emission current also increases. Fig 3 is the fluorescent display of electron emission of a-D films under different electric fields. Fig 3(a) shows the point emitting of a-D film under the electric field of about 5 ~ 8 V/μm. The area of the points is around the 0.1-0.5 mm^2. The points distribute on the whole surface of the a-D film. The phenomenon is quite different from that described by V.L.Humphreys and co-workers. They observed that the edge of the CVD diamond films had high work function, so the points displayed at the certre[22]. Fluorescent image show the whole surface electron emission of the a-D film in the area of 2×4 mm^2 under electric field about 10-12 V/μm (see fig 3(b)). The emission current was set up about 50 μA, showing that the emission current is stable, and almost made no difference after several days. Fig 4 is the current-field (I-E) characteristic and fig 5, Fowler-Nordheim (F-N) plots for emission currents of the film. The emission current can reach 0.9 μA at applied field as low as 1 V/μm, and the emission current density can be obtained above several mA/cm^2 at applied field no more than 20 V/μm.



(a) Under the electric field of 5-8 V/μm (b) Under the electric field of 10-12 V/μm

Fig 3 Fluorescence display of electron emission of amorphous diamond

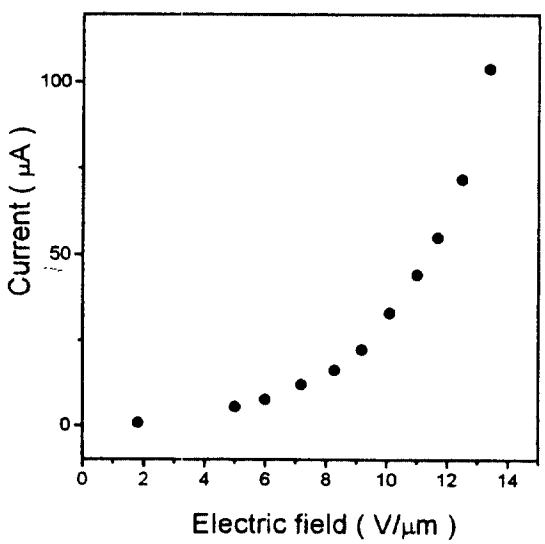


Fig 4 I-E characteristic of amorphous diamond film

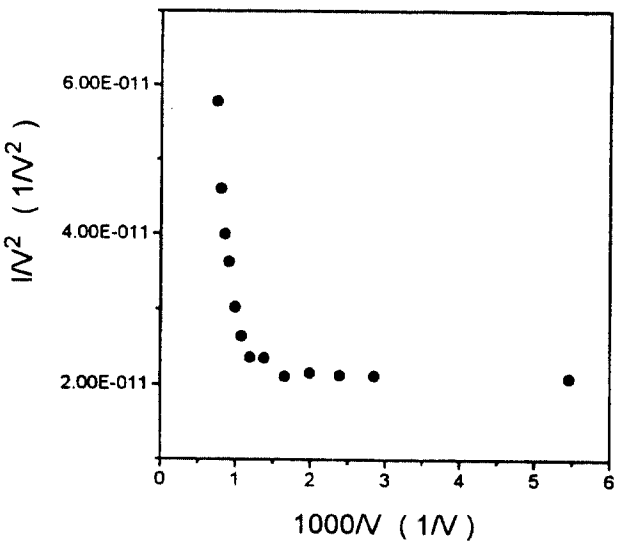


Fig 5 Fowler-Nordheim plots of amorphous diamond

From the above results, it is indicated that field emission properties of a-D film prepared by us are superior to those of a-D film and other forms of carbon have been considered previously:

(1) The emission current is more stable;

(2) The electron field emission is uniform;

(3) The film working life seems to be long;

(4) The turn-on field is less than 1 V/μm;

(5) The emission current density can obtain several mA/cm^2.

It has been analyzed that the graphite content in the diamond films is crucial for creating conduction channels between the substrate and the diamond surface[22]. Negative electron affinity and certain content of graphite are the two factors contribute to the fine emission properties of diamond films[3]. For a-D film prepared by FAD, only small content (<10%) of graphite exists in it. But it possesses very low turn-on field and high current density. Over limited ranges, the current density obeys the Fowler-Nordheim equation for field emission as follows[23]:

$$J = A \cdot (\beta E)^2 \cdot \exp(-B\phi^{3/2}/\beta E) \qquad (1)$$

where J is the current density in A/m^2, ϕ is the work function in eV, E is the electric field in V/m, β is the field enhancement factor at sharp geometries, $B=6.8\times10^9$ and $A=1.4\times10^{-2}$. The field enhancement factor β can be assumed of 1. From fig.5, it can be calculated that the work function ϕ is 0.025-0.05eV. It is very small compared to Mo and Si, which are the active materials commonly applied in electron industry. They have work function of 4-5eV. And is also smaller than that of high quality hot filament CVD diamond films[24].

Though the existence of the graphite is a intrinsic characteristic of the diamond films[25], from our results, we can say that its content in the matrix should be limited. B.S.Satyanarayana and co-workers have studied that turn-on field of FAD a-D films decreased with increasing sp^3 content, and they have obtained a maximun sp^3 content of 80% with a threshold field of 8V/μm, which is higher than ours[18]. We can conclude that small content of graphite (<10%) can provide high carrier density. High sp^3 content results in low work function of the surface, so decreases the electron affinity of a-D film. We have obtained/observed whole face uniform emitting of the a-D

film (see fig 3), which is demonstrated that the work function at every part of the surface mustn't make a great difference. It is relatively uniform. This characteristic makes it preferable to provide a-D film in flat panel display. Course shape and nonuniform composition of the surface of CVD diamond films result on nonuniformity of emission current and point emitting, and often cause vacuum arc to disrupt the films[26].

We have obtained and analysed the good electron emission properties of undoped a-D film. It can also be doped either n- or p-type film because of its easily doping capacity[27]. This work is continuing.

4 Conclusions

In summary, high sp^3 content hydrogen-free a-D films prepared by FAD process show better field emission properties than those of CVD diamond and high sp^3 content but hydrogenated a-D films. The electron emission current increases and the turn-on field decreases increasing sp^3 content in the a-D films. We have obtained whole face emitting image of the films. It can emit electrons under the emission field of less than 1V/μm. A current density as high as several mA/cm^2 is achieved. a-D film as a low electric field, high current density cold cathode material has many potential applications in vacuum electronics and flat panel displays.

Acknowledgement

This work is supported by national high technology program ("863") of China.

References

1 A.Ghis, R.Meyer, P.Ramband, F.Levy, and T.Lerous, IEEE Trans.Electron Devices ED-38, 2320 (1991)

2 N.S.Xu,Y.Tzeng,and R.V.Latham,J.Appl.D26,1776(1993)

3 N.S.Xu,R.V.Latham and Y.Tzeng,Electron.Lett.29,1596(1993)

4 N.S.Xu,Y.Tzeng,and R.V.Latham,J.Appl.D27,1988(1994)

5 C.Wang,A.Garcia,D.C.Lngram.M.Lake,and M.E.Kordesch,Electronics Lett.27,1449(1991)

6 M.W.Geis,N.N.Efremow,J.D.Woodhouse,M.D.McAleese,M.Marchywka.D.G.Socker,and J.F.Hochedez,IEEE Electron Devices Lett.12,456(1991)

7 J.Lee,K.Liu,and I.Lin,J.Appl.Phys.82,3310(1997)

8 K.Okano,K.Hoshina,M.Iida,S.Koizumi,and T.Inuzuka,Appl.Phys.Lett.64,2742(1994)

9 J.lin,V.V.Zhirov,A.F.Myers,G.H.Wojak,W.B.Choi,J.J.Hren,S.D.Wolter,M.T.McClure,B.R.Stoner, and J.T.Glass,J.Vac.Sci.Technol.B13,422(1995)

10 H.K.Schmidt,M.H.Clark,I.Yee,and N.Kumar,Abstract for the SID Manuf.Conference,1994,p.21

11 J.Robertson,Thin Solid Films 296, 61(1997)

12 J.C.Augus and C.C.Hayman,Science 241,913(1988)

13 K.E.Spear,J.Am.Ceram.Soc.72,171(1989)

14 Y.Mori,Y.Yokota,J.S.Ma,H.Kawarada,I.Ito,and A.Hiraki,Diam.Film Technol.12,93(1991)

15 W.R.L.Lambrecht and B.Segall,J.Mater.Res.3,696(1992)

16 B.B.Pate,Surf.Sci.165,83(1986)

17 K.C.Park,J.H.Moon,S.J.Chung,M.H.Oh,W.I.Milne,J.Jang,J.Vac.Sci.Technol.B15, 426(1997)

18 B.S.Stayanarayana,A.Hart,W.I.Milne,and J.Robertson,Appl.Phys.Lett.71,1430(1997)

19 J.Roberton,E.P.O'Reilly,Phys.Rev.B35,2946(1987)

20 M.Q.Ding,A.F.Myers,W.B.Choi,R.D.Vispute,S.M.Camphausen,J.Narayan,J.J.Cuomo,and J.J.Hren,J.bruley,J.Vac.Sci.Technol.B15,840(1997)

21 P.J.Martin,S.W.Filipczuk,R.P.Netterfield,J.S.Field,D.F.Whitnall,and D.R.Mckenzie,J.Mat.Sci.Lett.7,410(1988)

22 V.L.Humphreys and J.Khachan,Electron.Lett.31,1018(1995)

23 R.H.Fowler and L.W.Nordheim,Proc.R.Soc.London A119,173(1928)

24 V.V.Zhirnov,E.I.Givargizov,and P.S.Plekhanov,J.Vac.Sci.Technol.B13,418(1995)

25 W.Zhu,C.A.Fandall,A.R.Badzian,and R.Messier,J.Vac.Sci.Technol.A7,2315(1989)

26 M.G.Aucoua,J.Vac.Sci.Technol.B14,1918(1996)

27 K.Okano,Appl.Phys.A51,1731(1991)