CARBON NANOTUBE CATHODE ON METAL SURFACE FORMED WITH BGA BALLS

S.S. Max Chung[*], B.R. Huang[**], C. C. Chang[**], C. S. Fu[***], Y. Y. Chang[***], E. L. Chou[***], S. W. Lai[***], J. M. Chiou[***]

[*]Department of Electronic Engineering, Southern Taiwan University of Technology, Tainan, Taiwan, maxchung@so-net.net.tw

[**]Department of Electronics Engineering, National Yunlin University, Doliou, Taiwan

[***] Display Technology Center, Industrial Technology Research Institute, Hsinchu, Taiwan

ABSTRACT

Carbon nanotube (CNT) is the primary field emission source in many new applications, but there have been limited reports on direct growth of CNT on metal surface with CVD method with good electrical contact and surface adhesion [1]. We propose the use of BGA balls to bond CNTs grown with CVD method on Si wafer onto a metal substrate and form a grid array of emission source. Because of the low melting point (185ºC) of the BGA ball and its highly matured low cost production technique and physical properties compatible with the IC packing industry, this method can manufacture very large area of metal-CNT cathode with excellent field emission characteristics. Multiple samples of such cathode show turn on field (defined at 1μA/cm^2 current density) from 1.05- 1.48 V/μm, and field enhancement factor β ranging from 2500-3200. Optimum bonding time for this CNT growth condition at 63 MPa pressure is around 90 seconds.

Keywords: carbon nanotube, field emission, cathode, ball grid array

1 INTRODUCTION

Since the discovery of CNT, applications like sensors, Scanning Probe Microscope, hydrogen storage, fuel cell membrane, Field Emission Display (FED), and microwave tube have been developed. Most of these applications involve using the excellent field emission capability of CNT, and because field emission current depends highly on the properties of CNT, many methods were developed to purify CNT, to synthesize metallic CNT, to separate metallic CNTs from semiconductor CNT, and to obtain Single-walled Carbon Nanotube (SWCNT). However, a practical field emission device has to integrate CNT into its surrounding, which imposes different restrictions on CNT properties and manufacturing techniques.

For nanoelectronics applications, the ability to deposit *P* or *N* type CNT on designated position with metal forming a ohmic contact instead of a rectifying Schottky contact is essential, so far this has been achieved in selected device, but not on a large scale complicated circuit.

In FED or microwave device, often a gate with diameter of tens of μm holes to regulate field emission current is placed in front of the CNT cathode, and a metal stripe electrode is placed beneath the cathode to deliver current. Low turn on field and large field emission current is the desired property of such device, also a strong adhesion between CNT and the substrate (particular in microwave device where a strong field exists) and the possibility to manufacture this in larger area (>40") for FED in a low cost fashion are important. Although it is possible to grow CNT directly inside such structure today, uniform direct grow on practical large area is not available yet due to difficulty in producing a uniform large area plasma, and for it to penetrate inside tens of μm small holes simultaneously. Current prevailing method for CNT-FED is screen printing, and spraying for microwave cathode, which have issues like non-uniformity and low emission sites.

We devise a new method to manufacture metal cathode for microwave device (and FED) by hot-bonding CVD grown CNT with Ball Grid Array (BGA) Tin alloy spheres located on a pre-designated position on metal surface and forms a suitable cathode for microwave device. The turn on field (defined at 1μA/cm^2 current density) is as low as 1.05-1.48 V/μm, the forming temperature is only 200 ºC, the field enhancement factor β reaches 2500-3200, and the dJ/dE is around 1.28 MS/cm.

2 EXPERIMENT

A. Preparation of the CNT

A Fe catalyst layer is sputtered with Magnetron sputter on an *N* type Si substrate under 50 mTorr Argon pressure at 40 sccm gas flow rate for 5 minutes. The substrate is then placed in a high temperature oven filled with N_2 and C_2H_2 at 100 and 30 sccm flow rate. The sample is then heated to 700 ℃ for 10 minutes to grow CNT. The diameters of the CNTs are between 20-40 nm and the average length is about 30 μm. They are Multi-walled Carbon Nanotube (MCNT) and are mixture of both metallic and semiconductor CNTs. Fig. 1 is the illustration of the CVD apparatus for CNT growth. Fig. 2 is the side view of the grown CNTs. Fig. 3 is the Raman spectrum of CNTs. The

D to G band intensity ratio is about 0.75, which indicates well formed crystalline structures outnumber random ordered carbons.

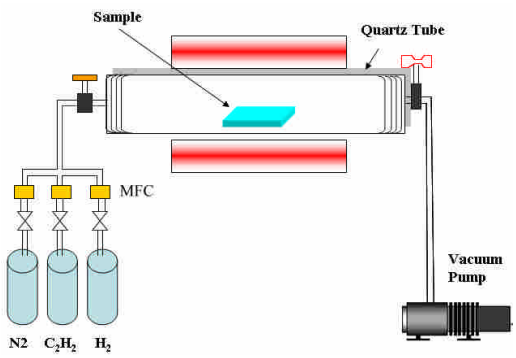

Fig. 1 The illustration of the CVD apparatus for CNT growth.

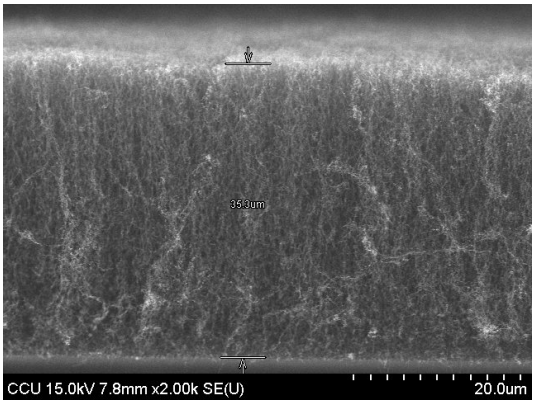

Fig. 2 Side view of the CNT grown on Si substrate with Fe as catalyst

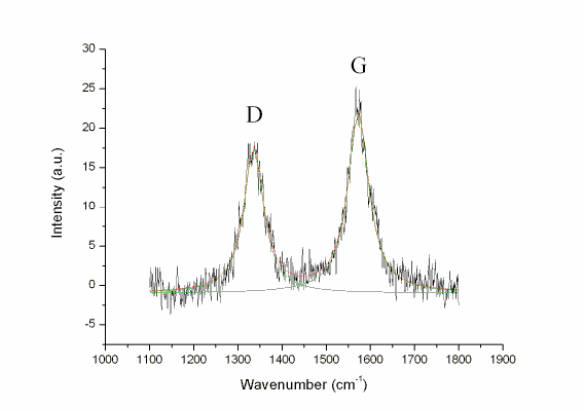

Fig. 3 The Raman spectrum of the CNT. The higher G band intensity indicates well formed crystalline structures outnumber random ordered carbons.

B. Bonding of the CNT and BGA Tin Alloy Sphere

A cupper substrate is pre-drilled with four 0.5 mm holes and sprayed with 0.5 mm diameter BGA balls (Sn63/Pb37) such that half of the balls are exposed above the surface. Then a Si substrate covered with CVD grown CNTs is flipped upside down and pressed onto the balls with 6.3 MPa pressure while heated to 200 ℃ (melting point of the ball is 185 ℃) for certain time.

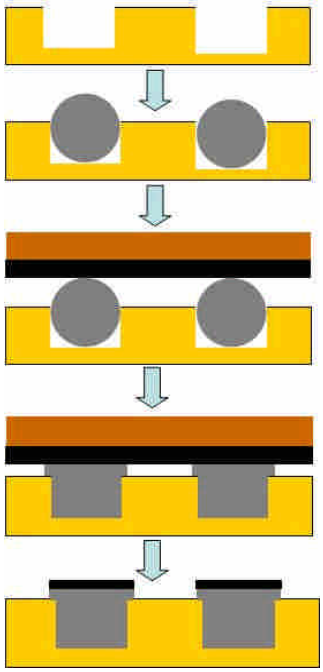

Fig. 4 Illustration of the CNT transfer process. Si substrate covered with CNT is pressed onto BGA balls at at 200 ℃ and 6.3 MPa pressure to hot-bond the CNT with melted balls.

C. Field Emission Current Measurement

Field emission current is measured in a diode type setting inside a vacuum chamber with better than $1x10^{-6}$ Torr base pressure with Kethley 237 high voltage precision meter.

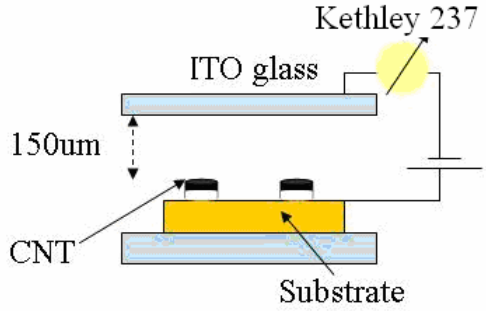

Fig. 5 Illustration of the field emission current measurement set up.

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3 RESULTS

Fig. 6 are the optical microscope pictures of the transferred results on four bonding time: (a) 30 s, (b) 60 s, (c) 90 s, and (d) 120 s. We can see that too short bonding time leads to only few CNTs transferred to the ball, while too long a time leads to smearing of the ball. The 90 s sample yields the best result under this specific pressure.

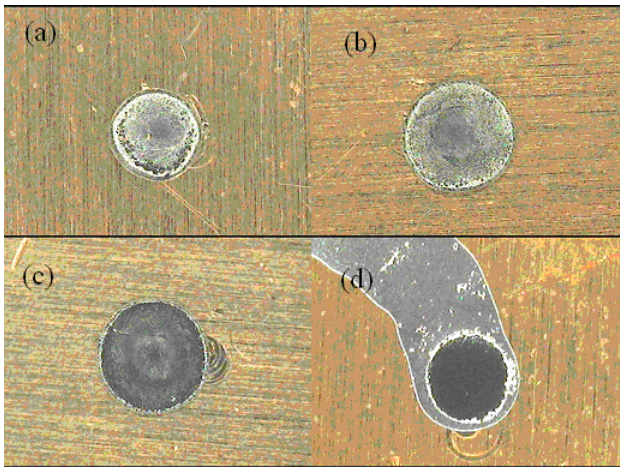


Fig. 6 Optical microscope picture of the transferred results on four bonding time, (a) 30 s, (b) 60 s, (c) 90 s, and (d) 120 s.

Fig. 7 to Fig. 10 are the SEM pictures of the transferred CNTs on the ball surface at different bonding time. As the bonding time increase, more CNTs are bonded onto the Sn ball surface, but 120 s causes the ball to completely melt and flows away, therefore 90s is the optimum bonding time.

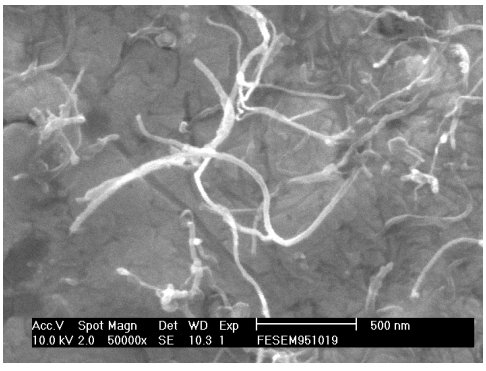


Fig. 7 The SEM of the 30s sample.

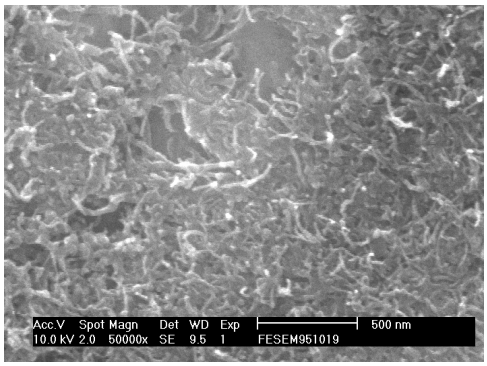


Fig. 8 The SEM of the 60 s sample.

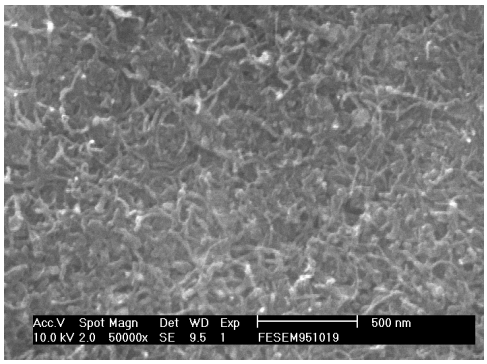


Fig. 9 The SEM of the 90 s sample.

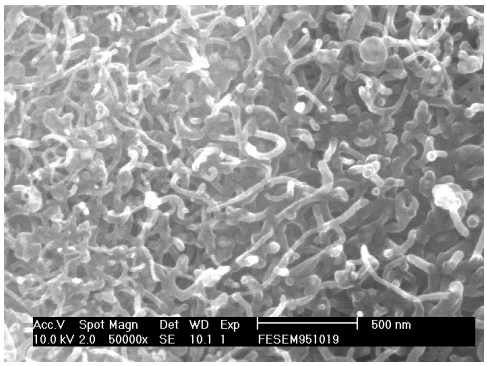
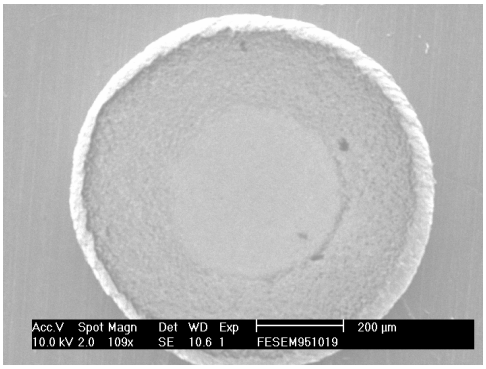
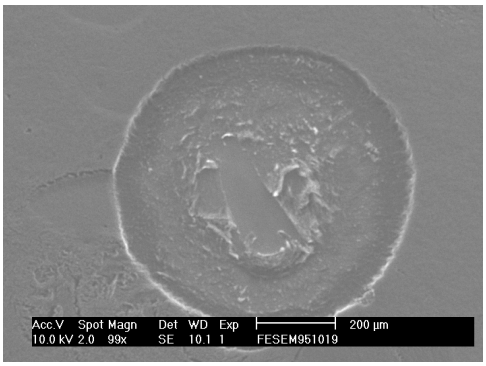


Fig. 10 The SEM of the 120 s sample.

Fig. 11 (a) is the SEM picture of the 90 s sample showing the whole ball surface covered with the transferred CNTs, and Fig. 12 (b) is the SEM picture of the Si surface after the transfer process. A clear circle of CNTs is seen ripped off the Si substrate.



(a)



(b)

Fig. 11 The SEM of the 90 s sample. (a) CNTs on the Sn balls, (b) SEM of the Si substrate after the transfer.

Fig. 12 is the field emission current density J versus applied external field E curve of the transferred samples. As the bonding time increases, the turn on fields decrease from more than 3.5 V/ μ m to 1.025 V/ μ m, which are much better than plain CNT cathode. The best turn on field is the 120 s sample, which might be the result of most CNTs are bonded in this case.

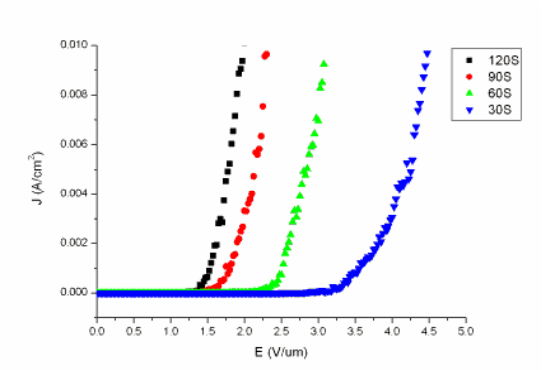


Fig. 12 The field emission current density J versus applied external field E curves of the transferred samples.

Fig. 13 is the Fowler-Nordheim figures of the transferred samples. The shorter the bonding time, the steeper is the curve, which indicates a higher field enhancement factor β. The best β value is the 30 s sample which reaches 3908. This fact indicates as the CNTs are pressed for a longer time, they are more flat to the surface, hence a lower field enhancement factor.

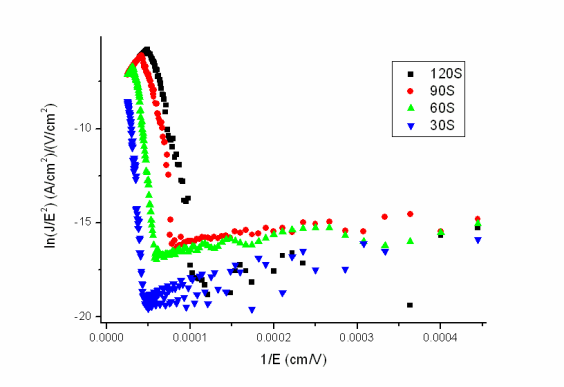


Fig. 13 The Fowler-Nordheim figures of the transferred samples.

4 CONCLUSION

We demonstrate a simple hot-bonding method to transfer CVD grown CNTs on to metal surface to form a field emission cathode. The turn on field of such device is significantly lower than plain CNT cathode, although the field enhancement factor β is also lower. The separation of the CNT growth process and the metal cathode bonding process enables one to control of the CNT property and the cathode manufacture process separately. The high CVD stage can proceed in high temperature range to ensure a good quality CNT growth, and location of the field emission sites together with field emission intensity can be controlled in the low temperature bonding process. A large field emission cathode for FED or microwave tube can be made with repetition of this process, and the defective sites can be repaired with reflow of the ball to remove and replace with new ball.

REFERENCES

[1] S. Talapatra et al., "Direct Growth of Aligned Carbon Nanotube on Bulk Metals", *Nature Nanotechnology*, 22 Oct. 2006.