高密度電漿之後處理對奈米碳管場發射特性之影響

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摘　要

奈米碳管(Carbon Nanotubes, CNTs)，因為具有極好的高寬比、小的曲率半徑、良好的化學穩定性、以及很高的機械強度，所以已經被大量應用於場發射元件之製程上。奈米碳管陣列的場發射電流強烈依賴功函數及奈米碳管表面的幾何形狀，優異的場發射特性具有較低的場發射電場以及較高的場發射電流密度。

在場發射材料的合成部分，利用熱化學氣相沉積(Thermal Chemical Vapor Deposition)系統探討以鐵-鎳合金為催化金屬層，藉由控制奈米碳管成長的參數來合成不同形態的奈米碳管。此外由場發射的測試中可以發現，奈米碳管具有非常優異的場發射特性，然而密度較高(~10^{12}/cm^2)的奈米碳管因為電場之遮蔽效應(screening effect)，使得場發射特性並不

因其具有較高密度之場發射源而變好。此論文為了進一步改善奈米碳管之場發射特性，提出了利用高密度電漿(氬、氧)蝕刻之後處理來改變奈米碳管之密度以降低電場之遮蔽效應。

實驗結果證實在適當的條件之下，奈米碳管之場發射起始電場可以大幅降低(由 3.1 V/μm 下降至 2.2 V/μm)，而場發射電流亦可大幅增加(由 2.35 mA/cm^2 上升至 48 mA/cm^2 當操作電場在 5 V/μm)。同時在 SEM 材料分析儀器分析下，證實了奈米碳管的分佈與表面型態的確因高密度電漿(氬、氧) 之後處理而改變。主要的原因是氬電漿以物理反應方式能夠有效地改變在奈米碳管上缺陷部分(非晶質碳)及揮發性污染物。氧電漿以化學反應方式改變奈米碳管表面結構如同去除非晶矽碳管,形成頂端的開口和減少奈米碳管層數，經由化學反應產生 CO、CO_2 等揮發性氣體而改善了奈米碳管的密度。

為了符合場發射顯示器低電壓操作的目的，實驗以半導體製程技術製作閘極來形成奈米碳管三極元件，並利用擇性成長奈米碳管的技術，以及控制奈米碳管成長密度的方式，將閘極操作電壓降低到 30 伏特。

Effects of High Density Plasma Post Treatments on the Characteristics of Carbon Nanotube Field Emission Displays

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ABSTRACT

Carbon nanotubes (CNTs) have been applied for the process of the field emission devices, because of their high aspect ratio, small radius curvature , high chemical stability, and high mechanical strength. Field emission current of CNT arrays depends strongly on the work function and geometry of the surface of CNT arrays. Excellent field emission properties of CNTs have been demonstrated lower turn-on electric field and higher filed emission current density.

For the synthesis of field emission materials, carbon nanotubes (CNTs) with various morphologies have been synthesized using thermal chemical vapor deposition (Thermal CVD) with Fe-Ni alloy catalysts via controlling the parameters of CNTs growth. The CNT emission arrays showed excellent field emission properties, however, the field emission properties of the high density CNTs ($\sim 10^{12}/cm^2$) degraded for the screening effect of the electric field. To improve the field emission properties of the CNTs, a novel post treatment process with plasma etching to reduce the screening effect of the electric field have been proposed.

The results depicted that the field emission properties can be upgraded with proper high density plasma treatment conditions. A plasma post treatment was introduced to

reduce the density of CNTs. Scanning electron microscopy (SEM) micrographs showed reduced densities of the CNTs, and the measurement of electrical characteristics revealed the improved field emission properties under suitable plasma conditions. The turn-on electrical field decreased from 3.1 V/μm to 2.2 V/μm, and the emission current density increased from 2.35 mA/cm^2 to 48 mA/cm^2 at the applied field of 5 V/μm. SEM have verified that the distribution and surface morphology of CNTs have been changed by HDPPT (argon , oxygen). The plasma exposure to argon (Ar) gas was performed in situ in order to modify all structural defects (non-crystalline carbon) and contamination of CNTs . Oxygen plasma removed the structure of carbon nanotubes on the surface, such as removing amorphous carbon, exhibiting the open-end on the tip and reducing the walls of carbon nanotube by way of chemical reaction, produce CO , CO_2 volatility gas and influence density of CNTs.

Finally, the CNT triode structures with the proposed plasma post treatments have been demonstrated to achieve the low voltage at 18V.

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Symbols

W_0 : the energy difference between an electron at rest outside the metal and an electron at rest inside the metal

W_f : the energy difference between the Fermi level and the bottom of the conduction band

ϕ : work function

J : the current density (A/cm^2)

E : the applied electric field (V/cm)

α : the emitting area

β : the local field enhancement factor

S : $Slope_{FN}$ the slope of a Fowler-Nordheim (F-N) plot

r : the tip radius of emitter tip

d : the emitter-anode(gate) distance

β` : geometric correction factor

E_{tip} : realistic electric field in the emitter tip

g_m : transconductance