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INVITATION

Mechatronics Seminars 2005
Focus on Nanosystems

Carbon Nanotube Based Field Emitter and Nanoelectronic Technology

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Room ML D28, at 4.15 p.m.
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Best Regards
Christofer Hierold, 6th April 2005

Abstract

The possibility of using carbon nanotubes (CNT) for field emission was first explored over eight years ago [1]. Since then there has been a very significant amount of activity directed towards understanding the field emission properties of carbon nanotubes as well as demonstrating their use in a range of field emission devices. The aim of this paper is to review some of this work in the context of assessing whether we are at a point where carbon nanotubes can be considered to be an established technology for field emission.

In terms of understanding, the field emission properties of CNTs have been explored in detail by a number of groups [2]. This work has elucidated the emission mechanism to be governed under certain conditions by adsorbed molecules on the tip. The barrier to emission seen in the Fowler-Nordheim plots of the filed emission data are particularly sensitive to such adsorbates. The electronic density of states at the Fermi level of single wall CNTs can also influence the emission properties. While the fine scale understanding of the FE mechanism from CNTs has been of great scientific interest, translating them into a practical field emission device technology has been more challenging. The main challenge has been the integration of CNT field emitters into an overall technology which includes the contact, gate and addressing components required in a complete device.

There have been two approaches which have evolved over the past few years to address the problem of integrating CNT emitters into FE devices. The first of these can be termed the 'macroscopic' approach where CNTs produced remotely in large quantities using industrial processes are blended into a carrier material, usually a photosenistive resin/polymer. The CNT/resin composite is then patterned into emitter regions using a selective photoexposure method [3]. A number of additional process steps are required to expose CNT emitters on the cathode surface and to 'activate' them. This approach has the advantage of utilising photolithography type methods which are common on FE device manufacture. However, the fine scale emission characteristics of the CNTs are submerged in a collective or averaged emission characteristics of many CNTs. The CNTs themselves could be multiwall, single wall or a combination of the two. The 'macroscopic' approach is particularly suited for large area FE devices such as displays where the emitter size is relatively large (10 – 100 μm) and due to the use of glass substrates the production process has to be kept below 300^{o}C. This CNT/resin process has been used for demonstrating impressive results from large area field emission displays.

The second approach can be termed 'microscopic' (where CNTs are grown directly into the field emission device in a selective manner. This exploits the feature of CNT growth which involves catalytic reaction with a transition metal (Ni, Co, Fe). By patterning the catalyst metal, it is then possible to determine the sites on which CNTs can grow. There have been a number of technological challenges which have had to be overcome to realize this concept in FE devices. These include the requirement that in an FE device with any form of addressing individual cathodes have to be isolated from each other except through connection via electrodes. This requires that no residual amorphous carbon(a-C) remains after the CNT growth process, as such a film of a-C will act to short the patterned metal regions. In addition for a three terminal FE device it is necessary for there to be no shorts whatsoever between the cathode and the gate. This requires that the CNT emitters to be grown in-situ with controllable heights and vertical orientation. Multiwall CNT technology which fulfils these requirements for FE cathodes has been developed [4,5]. Lithographic limitations govern the minimum catalyst region which can be patterned and hence the degree of fine control which can placed on the in situ CNT growth. We have demonstrated that micrometer scale catalyst regions can be engineered to yield well controlled selective growth CNTs in a FE back plane, Fig. 1. This technology has been scaled to the point where now it is possible to grow individual CNT emitters with integrated gates, Fig. 2. This technology is particularly suited for FE devices such as microwave amplifiers where the high current capability of CNTs can be used for realising compact cathodes with high current density. It is also suitable for small high definition FE displays where minimum beam divergence is required. The main challenge in expanding this technology into larger area devices is the requirement for fine lithography. In fact even with fine lithography it is not possible at present to deterministically grow SWCNTs (< 3nm dia.) with vertical orientation for FE devices. Even for moderate sized displays where

glass substrates are used, it is a further requirement that controlled CNT growth occurs at low temperature. Recent results show that this is a hurdle which can be overcome.

Deterministic growth of multiwall and single wall CNTs has however, evolved to the point where it is possible to explore them in a new generation of planar nanoelectronic devices based on FE. Here the CNTs field emit parallel to the substrate and are collected by anodes which are lithographically patterned to be close to, or below, the mean free path of electrons in ambient atmosphere. Such a structure is shown in Fig. 3.

Fig. 1 Aligned CNT emitters selectively grown In gate holes

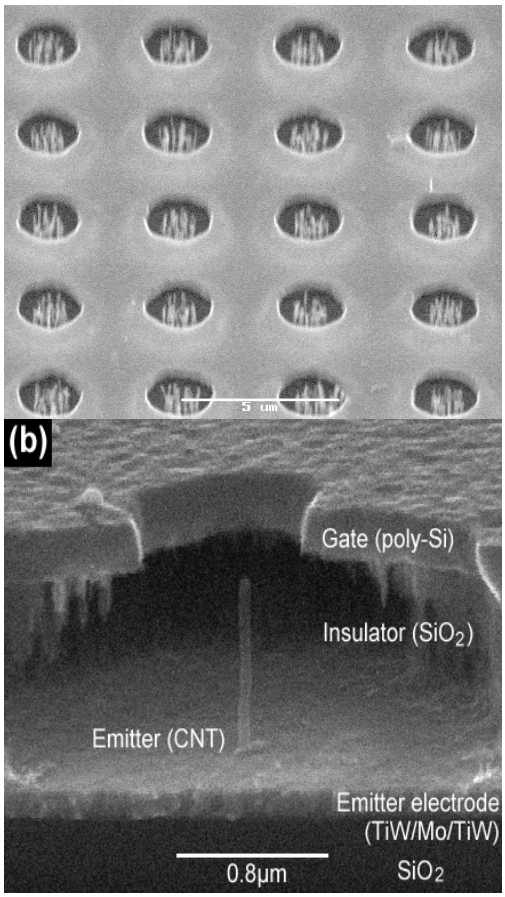

Fig.3 FE from a lateral CNT emitter in a nanoelectronic device

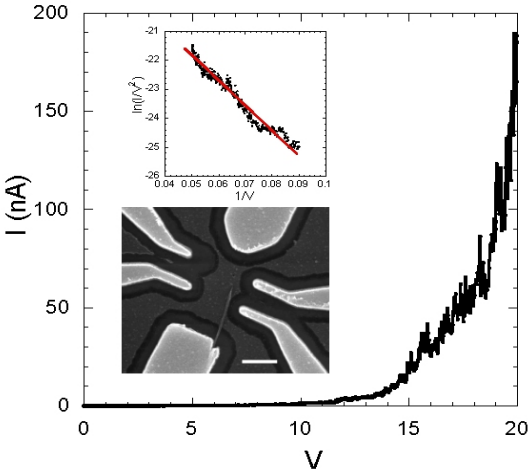

Fig. 2 A single CNT emitter with gating

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