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Nanoengineering of Materials for Field Emission Display Technologies

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The holy-grail in terms of flat panel displays has been an inexpensive process for the production of large area 'hang on the wall' television that is based on an emissive technology. As such electron field emission displays, in principle, should be able to give high quality pictures, with good colour saturation, and, if suitable technologies for the production of the cathodes over large areas were to be made available, at low cost. This requires a process technology where temperatures must be maintained below 450 ^{o}C throughout the entire production cycle to be consistent with the softening temperature of display glass. In this paper we show three possible routes for nanoscale engineering of large area cathodes using low temperature processing that can be integrated into a display technology. The first process is based on carbon nanotube-polymer composites that can be screen printed over large areas and show electron field emission properties comparable with some of the best aligned nanotube arrays. The second process is based on the direct large area growth of carbon nanofibres directly on to substrates held at temperatures ranging from room temperature to 300 ^{o}C, thereby making it possible to use inexpensive substrates. The third process is based on the use of excimer laser processing of amorphous silicon for the production of lithography free large area three terminal nanocrystalline silicon substrates. Each route has its own advantages, and flexibility in terms of incorporation into an existing display technology. The harnessing of these synergies will be highlighted together, with the properties of the cathodes developed for the differing technologies.

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1. Introduction

The flat panel display (FPD) market is one of the largest consumer electronic sectors, with sales within the US alone exceeding one billion dollars per annum. There are many competing FPD technologies for the flat displays, as shown in Fig. 1, with active matrix liquid crystal displays (AMLCDs) leading the way. For the larger flat displays, plasma display panels (PDPs) dominate, however, recent developments by Samsung have seen the emergence of AMLCDs with 52 inch diagonal screens. Samsung have also produced a prototype 38 inch full colour video rate carbon nanotube (CNT) display which shows all the positive attributes associated with field emission such as high brightness, high contrast, excellent viewing angles, low power consumption and large area. Other field emission display (FED) technologies based on metal 'Spindt' tips favoured by companies such as Candescent, Pixtech and Motorola have all delivered high quality displays. The UK based company, Printable Field Emitters, have opted for a screen printed graphite-silicon dioxide binder cathode to make their large area displays. Canon, Toshiba, Noritake, MEW and Sony all have their own field emission (FE) based technologies currently being developed for different segments of the market in this fast moving sector. All these companies see the merits associated with having a fully scalable FED technology, but need the cost of production to be lowered in order to enter the consumer market. Other emerging display technologies vying for honours in this sector include polymer and organic light emitting diodes (OLEDs), with no one technology being able to show all the attributes needed for a high quality large flat display that can be produced at a suitable cost and scale. [1]

FEDs operate in a manner which is a hybrid of the AMLCD and the PDP. The addressing of the picture elements is based on the matrix address system developed for AMLCDs, with the emissive display component showing similarities to the PDP output. Hundreds of multiply gated matrix addressed field emission cathodes emit electrons that hit a single pixel, whose brightness to a first order is controlled by the acceleration voltage applied between the cathode and the phosphor anode. The key physical parameters of importance in selecting a suitable cathode material for such an application are, in addition to its longevity, robustness and an ability to readily integrate into a production process, the requirement of being able to source high current densities at relatively low electric fields. In addition, an ability to produce uniform electron emission current-voltage characteristics with little or no hysteresis is also required. This tightness of the electron emission curves with applied field is important in being able to design matrix driver strategies with the required precision, where suitable offset voltages can be used for turning on gated cathodes. In terms of phosphors, standard high and medium voltage phosphors are at present preferred over the low voltage variety due to the reliability and testing that has been performed in both the CRT arena and plasma displays.

The results presented in this paper are based on three competing strands, all working towards a common goal of affordable large area FED cathodes. The first technology is associated with the production of inexpensive cathodes based on mixing CNT-polystyrene (PS) composites that are cast-able or screen printable over large areas. [2] Their performance as an electron source is tested against other competing nanotube (NT) emitters, as well as Spindt tips. The key marketable feature of CNT-composite emitters are reliability and costs, which compare favourably with the performance of other more expensive and complicated cathodes. We show the current density and threshold fields afforded by these cathodes are some of the best available in the published literature.

The second technology introduced in this paper is associated with the availability of a low temperature growth process for the production of carbon nanotubes and carbon nanofibres (CNFs). [3] In this case we show the structure of the deposited material is ideally suited for electron field emission, and due to the very low temperature plasma based growth process, can be easily incorporated into a large area display technology. We highlight the advantages associated with a direct in-situ cold cathode growth environment, that gives nanometre precision in the CNT/CNF growth due to the requirement of a suitable catalyst, with the correct dimensions. [4] Due to the low growth temperature the requirement of a barrier layer between the catalyst and the substrate to prevent the transition metal from diffusing may be relaxed. The plasma based growth process is also scalable to very large areas in an inexpensive manner, and can grow materials on non-uniform and non-conformal surfaces such as gated cathode tracks due to the catalytic plasma based growth process. The technology also lends itself to domestic lighting applications. [5]

The third technology is based on nano-silicon field emitters and was originally introduced in order to exploit a holistic approach to the production of FEDs. The idea being that as amorphous silicon and polycrystalline silicon thin film transistors (TFTs) were already being prepared over very large areas in AMLCDs, if the electron emission component of the FED could also be produced using the same material it would allow a seamless transition of the thin film silicon fabrication facilities to a FED technology. We show how amorphous silicon excimer laser crystallised over large areas can be used as a cathode material. The excimer laser treatment, at low energy densities, affects only the top few nanometres of the *a*-Si:H layer and produces nanocrystalline structures, which would give rise to the enhanced emission properties. This process is then extended to produce lithography free three terminal field emission structures using large area processes that lend itself to fully integrated low cost thin film silicon based cold cathode technology.

2. Electron field induced emission

Field emission is the extraction of electrons from a surface under the influence of an applied electric field. The front surface potential barrier for electron emission is reduced by the application of voltage V_a to an anode located at a distance D away. Far from the emitter surface the macroscopic field is simply V_a/D. For tip based structures this macroscopic field is enhanced in the neighbourhood of an emitter by a geometric field enhancement factor, β. This results in a local electric field which is larger than the applied field. The most common definition of the field enhancement factor, β, is the ratio of the local field to the applied field. In the case of an isolated vertically aligned CNT in the electrode geometry presented in Fig. 2(a), the local field depends on the height *h*, radius *r* and anode-substrate separation D. Shown in Fig. 2(b) are the results of a 2D electrostatic simulation for the variation of β with D for a three metallic tubes of heights 2, 4 and 6 μm capped with a hemisphere. It is apparent that the enhancement factor in this case is only constant (*i.e.* independent of the electrode geometry)