



Methods for producing electron emitter structures, the electron emitter structures produced, and field emission displays and field emission backlights incorporating the electron emitter structures

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Field of the invention

The present invention relates to methods for producing an electron emitter structure for a field emission display (FED), or a field emission backlight for a liquid crystal display (LCD), and also to the electron emitter structures, FEDs and field emission backlights so produced.

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Background of the invention

Field emission displays (FED) are among the most promising candidates for the next generation of displays. Field Emission Backlights for liquid crystal displays (LCD) also attract the interest of many researchers today.

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One well-known type of electron emitter structure of a FED, a Spindt type emitter, is shown schematically in Figure 1. A lower portion of the emitter comprises a glass substrate 1, covered by a lower electrode 2. A number of insulator elements 3 support gate electrode elements 4. This type of emitter has a small Mo cone 5, in electric contact with the lower electrode 2, as a cathode. When a large enough negative voltage is applied to the cone 5 (via the lower electrode 2) the electric field concentration at the top of the Mo cone 5 becomes high enough to expel electrons. The electrons are attracted across a gap to an upper portion of the FED, composed of an upper electrode (anode) 7, which is sandwiched by a phosphor layer 6 and a second glass substrate 8. The generation of light by the phosphor layer 6 can be controlled by controlling the voltages applied to the gate electrode elements 4, in particular so as to make certain areas brighter than others. If the gate elements 4 are omitted, the structure generates uniform light, and may also for example function as a uniform field emission backlight of an LCD.

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This emitter array is fabricated using vacuum-processing machinery in a photo-lithographic process which needs many masks. The Mo cone 5 is deposited with the substrate tilted, and then by rotating it. The series of process steps is very complicated and expensive, and it is difficult to make exactly the same cone shape for each of the many emitters in the array, which leads to uneven electron emission properties.

Another type of emitter, a Carbon Nano Tube (CNT), also attracts much interest. Figure 2 shows a schematic diagram of the CNT type FED. Elements having the same meaning as those in Figure 1 are denoted by the same reference numerals. The only difference is that a plurality of CNTs 9 are used as each cathode.

The CNTs are grown perpendicular to the surface of the substrate 1 and the electric field concentration is high at the top of the CNTs. Carbon is well known for its high electron emission property, so CNT is a suitable material for an electron emitter. However, the CNT are normally grown in a vacuum and usually high temperature is required to make good quality CNTs, so the process is expensive, and the substrate also expensive because it has to withstand high temperature during the process.

To solve the CNT-related problems which are mentioned above, some researchers have proposed a binder having the consistency of a paste and containing independent CNTs. Such a binder is pasted onto the substrate in place of the CNT of Fig. 2, and some of the CNTs in the paste happen to project above the binder surface, and work as cathodes. Unfortunately, this method makes it difficult to achieve even electron emission in the array, and also there is also high contact resistance between the electrode 2 below the CNT paste and each CNT. Additionally, the independent CNTs themselves are an expensive material.

Summary of the invention

The present invention aims to provide a new and useful electron emitter structure, and FED and field emission backlights, using the structure.

5 In general terms, the present invention proposes that a mask with a plurality of spaced-apart openings is formed on a surface of a substrate, and that the substrate is then chemically etched through the openings, whereby portions of the substrate proximate each of the openings are removed, leaving the surface with a plurality of spikes. Each of the spikes may function as an electron emitter. If the substrate itself is not composed of an electron emission
10 substance having suitable electron emission properties, a layer of such a material is deposited onto the structure. One suitable electron emission substance is DLC.

By selecting the properties of the mask and the etching conditions, the
15 geometrical properties of the spikes can be selected. Thus, certain embodiments of the invention make it possible to form spike structures which have an optimal pitch/height ratio. Isotropic chemical etching naturally tends to form a structure having a pitch/height ratio of substantially 2, which has been shown elsewhere to be ideal.

20 The electron emitter structure is furthermore obtained by less expensive methods than those suggested in the prior art discussed above, and without the need for CNT.

25 The substrate is preferably composed of a conductive material, and most preferably of aluminium (Al).

A preferred mechanism for forming the masks is by a process in which a first layer is formed onto the substrate, and then etched to form openings. The
30 mask material is then deposited into the openings, and the first layer is removed.

The process used to form the first layer may be anodization of aluminum oxide (AAO), in which the Al substrate is used as the anode in an

electrochemical reaction. This forms a layer of Aluminium oxide having pores, and the pores are then etched to enlarge them into openings where the substrate is exposed. In other words, the openings are formed by a process of "self-assembly".

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Thus, the entire operation of forming the electron emitter structure from a substrate is preferably conducted without the use of expensive processes like photo lithography.

- 10 The invention may be expressed in terms of a method for producing the electron emitter structure, or as the structure produced, or as devices incorporating the structure.

Brief description of the drawings

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An embodiment of the invention will now be described for the sake of example only with reference to the following drawings, in which:

FIG. 1 is a schematic diagram of the known Spindt type FED.

FIG. 2 is a schematic diagram of the known CNT type FED

- 20 FIG. 3, which is composed of Figs. 3(a) to 3(h), shows, using cross-sectional views, the steps of a process which is an embodiment of the present invention, to form spike structures on an Al substrate using AAO.

FIG. 4 shows schematically the anodization setup used in the embodiment of Fig. 3.

- 25 FIG. 5 shows schematically the filtered-cathodic-vacuum-arc (FCVA) deposition system used in the embodiment of Fig. 3.

Detailed description of the embodiment

- 30 Referring firstly to Fig. 3(a), the starting point of a method which is an embodiment of the present invention is a laminar substrate 10 composed of Al. The thickness of the Al substrate is 0.4mm (so that the substrate is an Al foil) and the purity of Al is 99.999%. As shown in Figure 3(b), a layer 11 of anodized aluminum oxide (AAO) is formed on one major surface of the Al

substrate 11 by an anodization step, followed by pore widening. The thickness of AAO layer is preferably less than $1\text{ }\mu\text{m}$. The AAO layer 11 is formed with many through-holes 12 which are perpendicular to the surface of the substrate 10.

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Figure 4 shows schematically the setup used to perform the anodization. The Al foil 10 is supported by a support structure 19 with one of its two faces exposed to an acidic solution 15 within a bath 14. $0.4\text{M H}_3\text{PO}_4$ is used as the acidic solution 15. The bath also contains a Pt wire 16, and an electric process is carried out in which the Al foil 10 functions as an anode and a Pt wire 16 as the cathode. A magnetic stirrer 17 is driven by a magnetic driver 18. A DC voltage is applied between the Pt wire 16 and the Al foil 10, for example 100V , and a layer of AAO is formed on the substrate 10. The AAO thickness is controlled by the anodization time, which may be 2mins.

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After the anodization, the pore widening process is conducted. In this process the surface of the Al substrate 10 having the AAO layer is soaked in $10\text{wt}\%$ H_3PO_4 solution for 70mins. This process enlarges the pores, to the extent that the pores become through holes 12. The resulting thickness of the AAO elements 11 (in the vertical direction of Fig. 3(b)) is about $1\text{ }\mu\text{m}$, the pore diameter is about 200nm and the pore pitch (i.e. periodicity of the pores) is about 250nm , such that the width of the elements 11 is about 50nm .

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As shown in Figure 3(c), Ti layers 20 are then deposited in the respective pores by sputtering. Their thickness is about 300nm .

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As shown in Figure 3(d), the AAO 11 is then removed completely using $10\text{wt}\%$ H_3PO_4 solution.

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As shown in Figure 3(e), the Al substrate 10 is etched using $10\text{wt}\%$ H_3PO_4 solution. In this process, the Ti layers 20 work as a mask and the etching proceeds isotropically as shown in this figure.

As shown in Figure 3(f), the parts of the Al substrate 10 below the Ti masks 20 are made thinner by etching. Eventually, as shown in Figure 3(g), the parts of the Al substrate 10 below the Ti masks 20 become too thin to support the Ti masks 20, and finally the Ti masks 20 are separated. The ratio of the pitch of the spikes and the height of the spikes (pitch/height) becomes about 2 because of the isotropic etching. This is significant because it has been reported in the paper Appl. Phys. A 83, 111–114 (2006), by Kim et al, entitled “Numerical study on the field emission properties of aligned carbon nano tubes using the hybrid field enhancement scheme”, that when the pitch/height ratio of CNT is about 2, the maximum current density is obtained if the top of the spike is very sharp.

As shown in Figure 3(h), a layer of DLC (diamond-like carbon) 21 is deposited on the Al substrate 10 by the filtered-cathodic-vacuum-arc (FCVA) method. DLC formed by FCVA is known for its high electron emission properties. In other embodiments, other low work function materials or low electron affinity materials may be deposited instead of DLC.

The FCVA deposition system is shown in Figure 5, where a carbon plasma 22 is produced through high current arcing 24 of a graphite cathode 23 in high vacuum conditions. A magnetic field produced by electromagnets 25 is created to steer the carbon plasma in a curved path towards the surface of the substrate 10, eliminating undesired macro-particles in order to produce a purer and denser film structure. Further electromagnets 26 perform a focusing function. The ion energy is controlled by the bias voltage, applied by a voltage generator 27, which is applied to a metal substrate holder (not shown) which holds the substrate 10. By optimizing the voltage bias during the deposition process, the film hardness, the film stress and the strength of adhesion can be controlled (as disclosed in US 6,031,239). Also the bonding structure of carbon ions can be controlled.

The structure produced in Fig. 3(h) can now be employed in a structure as shown in Fig. 1, replacing the cone 5 and the lower electrodes 2. If the gates 4

are omitted, the structure operates as a light-generator, such as a uniform field emission backlight for an LCD.

5 Note, however that nowadays many researches are trying to segment the backlight into many areas and to control the brightness of each area depending on a shown picture in order to increase the contrast of the shown picture and decrease the power consumption. Therefore even in systems in which the embodiment is employed as a backlight, the backlight may also be required to be controlled area by area.

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Although only a single embodiment of the invention has been described, many variations are possible as will be clear to a skilled reader.

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Claims

1. A method of forming an electron emitter structure, the method comprising:
 - 5 (a) forming on a surface of a substrate a mask with a plurality of spaced-apart openings;
 - (b) chemically etching the surface of substrate through the openings in the mask, until the surface of the substrate develops a structure with a plurality of spaced-apart spikes.
- 10 2. A method according to claim 1 further comprising a step (c) of depositing an electron emitter layer onto the surface of the substrate.
3. A method according to claim 1 or claim 2 in which the spikes are
 - 15 formed having a pitch/height ratio of substantially 2.
4. A method according to any preceding claim in which the substrate is aluminium.
- 20 5. A method according to any preceding claim in which step (a) is performed by a process in which:
 - (i) a first layer is formed onto the substrate, and then etched to form openings,
 - (ii) mask material is deposited into the openings, and
 - 25 (iii) the first layer is removed.
6. A method according to claim 5 in which the first layer is formed by using the Al substrate as the anode in an electrochemical reaction, thereby forming the first layer as an AAO layer having pores, and the pores are then
 - 30 etched to enlarge them into openings where the substrate is exposed.
7. An electron emitter structure having:
 - a substrate, one surface of the substrate being formed with a plurality of spikes;

an electron emitter material deposited over the surface of the substrate.

8. An electron emitter structure according to claim 7 in which the spikes have a pitch/height ratio of substantially 2.

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9. An electron emitter structure according to claim 7 or claim 8, in which the electron emitter material is diamond-like carbon (DLC).

10. A field emission display comprising the electron emitter structure of any of claims 7 to 9.

11. A field emission backlight for an LCD display comprising the electron emitter structure of any of claims 7 to 9.

15 12. An LCD display comprising a field emission backlight according to claim 11.