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(54) Single crystal field emission device.

(57) A field emission device (100) uses single crystals in order to eliminate grain boundaries within some or all of the electrodes (103, 104, and 205). The elimination of grain boundaries reduces susceptibility to damage, improves stability of the device (100), and improves uniformity and reproducibility among devices. In a preferred embodiment, the emitter and gate electrodes (103 and 104 respectively) are formed from a single crystal thin film (302). In other embodiments, other structures are employed wherein one or more of the electrodes (103, 104, and 205) are formed from single crystals.

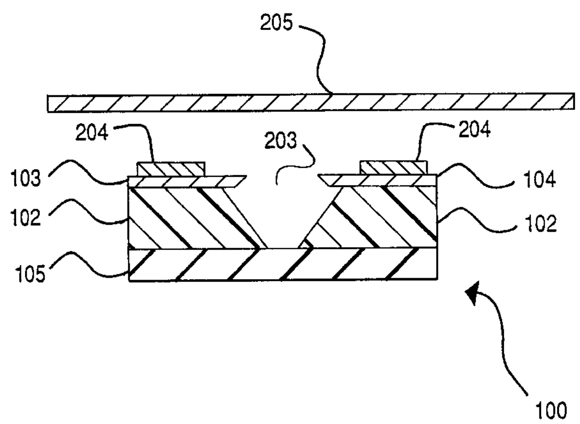

FIGURE 2

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This invention pertains to the field of field emission devices, and particularly relates to a device in which some or all of the electrodes are formed from single crystal material.

Field emission devices are microscopic electrical components which selectively emit electrons. Such devices 100, as shown in Figures 1a and 1b, generally comprise two electrodes: an emitter electrode 103 for emitting electrons and a gate electrode 104 for controlling the flow of electrons from the emitter electrode 103 depending on the electrical charge present at the gate 104. The electrodes are typically mounted on some kind of substrate 101 or 105 to provide support for the device, with a gap between the electrodes. A third electrode, the anode (not shown in Figures 1a and 1b), may also be present to receive the emitted electrons, although in some devices the gate electrode 104 serves as the anode.

Field emission devices have been known for several years to have many potential applications in commercial and military industry, such as: high-definition television; flat-panel video displays; radiation-hard thermally insensitive integrated circuits; microsensors; fast electron sources for vacuum tubes; and electron microscopes. However, there are a number of practical difficulties associated with such devices which have inhibited their widespread use. Three such problems are 1) their extreme sensitivity to damage, 2) their instability evidenced by a tendency towards microstructure changes with use, and 3) the difficulty of manufacturing such devices with sufficient uniformity and reproducibility. The following references detail these problems, and describe the state of the prior art in the manufacture of emission devices.

U.S. patent 3,947,716 disdoses a field emission tip and process wherein a metal adsorbate is selectively deposited on the tip to create a selectively faceted tip with the emitting planar surface having a reduced work function and the non-emitting planar surfaces having an increased work function, thus yielding improved performance. The patent disdoses the use of a single crystal to fabricate emission tips, but the reason for single crystal use in emission tips has traditionally been to facilitate fabrication of a cone-shaped emitter. The patent does not mention the use of single crystals for the other electrodes of the device, nor does it suggest the use of single crystals in conjunction with thin film emitters or for stability and arc damage resistance.

S.M. Spitzer and S. Schwartz, "A Brief Review of the State of the Art and Some Recent Results on Electromigration in Integrated Circuit Aluminum Metallization", J. Electrochem. Soc. v. 116, p. 1368 (1969), discusses some of the problems associated with electromigration in integrated circuit devices. Electromigration phenomena have been found to cause instability and susceptibility to damage in emission devices. The artide does not mention the use of single crystal material to reduce electromigration problems.

J.E. Wolfe, "Operational Experience with Zirconiated T-F Emitters", J. Vac., Sci. Technology v. 16, p. 1704 (1979), discusses the characteristics of an electron gun which uses a cathode-filament structure with a needle-shaped cathode. It discusses some techniques for improving performance and extending device lifetime, but does not mention grain boundaries or single-crystal structures.

G.W. Jones, C.T. Sune, and H.F. Gray, "Self-Aligned Vertical Field Emitter Devices Fabricated Utilizing Liftoff Processing", 3d Int'l Vacuum Microelectronics Conf., July 23-25, 1990, Monterey, CA, poster 1-2, sets forth a method of fabricating vertically self aligned field emitter cathodes and extraction electrodes utilizing liftoff process and anisotropic silicon etching. This technique involves first forming silicon dioxide islands on heavily doped N+ silicon and then using those islands as etch masks to form flat topped pyramids with silicon dioxide overhanging caps.

R.B. Marcus et al., "Formation of Sharp Silicon and Tungsten Tips", 3d Int'l Vacuum Microelectronics Conf., July 23-25, 1990, Monterey, CA, paper 1-3, describes a variation on a previously known procedure for forming atomically-sharp silicon tips of between 10° and 15° half-angle by utilizing oxidation inhibition at regions of high curvature for silicon tips. The variation employs a chemical vapor process to form similar tips out of tungsten.

K. Warner, N.M McGruer, and C. Chan, "Oxidation Sharpened Gated Field Emitter Array Process", 3d Int'l Vacuum Microelectronics Conf., July 23-25, 1990, Monterey, CA, poster P-25, discusses a process for fabricating gated field-emission cathodes with sharp tips by oxidation.

D.W. Branston and D. Stephani, "Field Emission from Metal Coated Silicon Tips", 3d Int'l Vacuum Microelectronics Conf., July 23-25, 1990, Mon-terey, CA, paper 5-4, describes emission properties of various groupings of emitters formed as arrays of silicon tips coated with various refractory metals by physical vapor deposition techniques.

The methods set forth in the above-referenced artides generally represent the state of the art in manufacturing techniques for emission devices.

S. Bandy, C. Nishimoto, R. LaRue, W. Anderson, and G. Zdasiuk, "Thin Film Emitter Development", Technical Digest of IVMC 91 (August, 1991), p. 118, published within one year of the instant patent application, describes an emission device manufacturing method using thin films. It sets forth the properties and advantages of thin film emitters in comparison with traditional cone-shaped emitters. These two structures for emission devices are shown in Figures 1a and 1b of the instant patent application. Figure 1a shows a well-known cone emitter structure, in which a cone-shaped emitter electrode 103 is mounted on a conducting substrate 101 (as stated in "Thin Film Emitter Development", "virtually all structures reported in the literature use conducting substrates."). Devices of this type are commonly manufactured using etching or metal dosure techniques. Figure lb shows the newer "edge emitter" structure discussed in "Thin Film Emitter Development", in which an edge of the emitter 103 protrudes from between an insulator 102 and a metal overlay 106. This structure usually employs an insulating substrate 105. Edge emitters offer several potential advantages over cone-shaped emitters, including improved reproducibility and uniformity, high current densities, and high frequency performance. Even with these advantages, however, the three problems mentioned above persist.

Although it has been known in the art for some time that the use of single crystals facilitates fabrication of cone-shaped emitter electrodes, the benefits of single crystals in improving stability and uniformity and reducing damage have not been previously known. Accordingly, they have not been used for the other electrodes of the device (namely the gate and the anode), nor have they been used for non-cone-shaped emitters. None of the prior art suggests the novel features of the present invention, in which single crystals are used to form some or all of the electrodes of the device, not just cone-shaped emitters, in order to alleviate the problems of uniformity, reproducibility, stability, and sensitivity to damage.

The present invention describes a field emission device (100) and manufacturing method which minimize the problems of sensitivity to damage, instability, and lack of uniformity, by forming some or all of the electrodes of the device out of single crystals having no grain boundaries.

Research conducted in connection with development of the present invention has shown that grain boundaries within the electrodes (103, 104, and 205) of field emission devices (100) contribute to all three problems described above. One effective way of eliminating grain boundaries within an electrode (103, 104 or 205) is to fabricate the electrode (103, 104 or 205) from a single crystal. Consequently, the present invention describes a field emission device (100) that uses single crystal electrodes in order to avoid the presence of grain boundaries within electrodes (103, 104 or 205), thus minimizing arc damage and improving stability, reproducibility, and uniformity. Single crystals may be used on any or all of the electrodes (103, 104 or 205) of the device (100).

In a preferred embodiment, the emitter and gate electrodes (103 and 104 respectively) are formed from the same single crystal thin film, by a method which etches a gap (203) in the crystal to define the two electrodes (103 and 104). Alternatively, the emitter and gate electrodes (103 and 104 respectively) can be formed from two independent single crystal thin films, or the electrodes (103 and 104) can be configured using any other emission device structure, including, for example, traditional cone emitter structures. In any of these alternatives, the gate electrode (104), the emitter electrode (103), or both may be single crystal. Optionally, a single crystal anode electrode (205) may also be used to further reduce the aforementioned problems.

These and other more detailed and specific objects and features of the present invention are more fully disclosed in the following specification, reference being had to the accompanying drawings, in which:

Figure 1a is a sectional diagram of a field emission device 100 having a cone-shaped emitter 103 according to the prior art.

Figure 1b is a sectional diagram of a thin film field emission device 100 having an edge emitter structure 103.

Figure 2 is a sectional diagram of a single crystal thin film emission device 100 in accordance with a preferred embodiment of the present invention.

Figures 3a through 3f illustrate a preferred method of manufacturing the single crystal thin film emission device 100 according to the present invention. These Figures are sectional diagrams of the device 100 at six stages of the preferred manufacturing process.

Referring now to Figure 2, there is shown a sectional diagram of a preferred embodiment of a field emission device 100 according to the present invention. Two insulators 102 made from, e.g., aluminum gallium arsenide are deposited on an insulating substrate 105 made from, e.g., gallium arsenide. The insulators 102 are shown spaced apart, but they need not be. The emitter and gate electrodes, 103 and 104 respectively, are formed from a single thin film of e.g., heavily doped gallium arsenide and rest on the insulators 102, so that a gap 203 is formed between the two electrodes. Ohmic contacts 204 are fastened to the emitter and gate electrodes to facilitate electrical contact with the device. An anode electrode 205, separated from the other components of the device and also formed from a single crystal, may also be present to collect the emitted electrons, or, alternatively, the gate electrode 104 may function as an anode.

Referring now to Figures 3a-3f, there is shown a preferred method for manufacturing field emission devices 100 according to the present invention. One skilled in the art will readily recognize that alternative embodiments of this method may be employed without departing from the principles of the invention described herein.

In Figure 3a, the starting material for the process is shown. There is provided an insulating substrate 105 of gallium arsenide. Deposited on the substrate is a buffer layer 301 of aluminum gallium arsenide, approximately 5 microns thick. Finally, on the buffer layer 301 is a single crystal thin film (approximately 1000 angstroms thick) of conducting material 302, preferably heavily doped gallium arsenide. Other materials and thicknesses may be used.

In Figure 3b, a layer of photoresist 303 is applied on top of the conducting layer 302, according to well-known device manufacturing techniques. The photoresist is applied in a pattern which will eventually define the placement of the electrodes 103 and 104 on the final device, by leaving gaps where the conducting material 302 is to be removed.

In Figure 3c, the conducting layer 302 is etched according to well-known device manufacturing techniques. Wherever photoresist 303 is present, the conducting layer 302 remains intact, but where there is a gap in the photoresist 303, the conducting layer 302 is etched away. In this way, two electrodes 103 and 104 are formed, with a gap 203 between them. Electrode 103 will eventually become the emitter and electrode 104 will become the gate.

In Figure 3d, the photoresist 303 is removed.

In Figure 3e, the buffer layer 301 is etched out under the gap 203, so that there is some overhang of the electrodes 103 and 104. The buffer layer 301 thus becomes two aluminum gallium arsenide insulators 102. In an alternative embodiment, the buffer layer may not be etched out, or may only be partially etched out, so that insulators 102 are touching.

In Figure 3f, ohmic contacts 204 are attached to the electrodes 103 and 104 so that electrical connections can be made to the device 100. An anode electrode 205 is also shown, although this is optional; if no anode 205 is present, the gate electrode 104 acts as an anode. The anode 205, if present, may be made of heavily doped gallium arsenide, or gold, or any other conducting material. It may be formed from a single crystal, although this is not necessary. It may or may not be formed from a thin film, and may even be formed from the same film as the other two electrodes (for example, in a coplanar arrangement).

Other materials may be used in place of those mentioned. In addition, the emitter and gate electrodes, 103 and 104 respectively, may be formed from two separate single crystal thin films, rather than from one piece 302. The invention may be practised with other device structures wherein differently shaped electrodes, such as the traditional cone-emitter structure of Figure 1a, are employed in place of thin film electrodes. Finally, the invention may be practised using single crystals for some but not all of the electrodes.

The gate electrode is formed from a single crystal. The emitter electrode can also be formed from a single crystal, either the same as that of the gate electrode or another single crystal. The same applies to the anode electrode. The crystal or any of the crystals as appropriate can be thin films, preferably of gallium arsenide. The emitter is preferably cone shaped.

Claims

1. A field emission device comprising:
   an emitter electrode for emitting electrons; and
   a gate electrode for controlling the electron emission, formed from a first single crystal; wherein there is a gap between the emitter electrode and the gate electrode.

2. The device of claim 1, wherein the emitter electrode is formed from the first single crystal.

3. The device of claim 2, wherein the first single crystal comprises a thin film.

4. The device of claim 3, wherein the thin film is formed from gallium arsenide.

5. The device of claim 3, further comprising an anode electrode spaced apart from the emitter electrode to receive the electrons from the emitter electrode.

6. The device of claim 5, wherein the anode electrode is formed from the first single crystal.

7. A field imaging device as claimed in claim 1 further comprising an insulating substrate, a first insulator mounted on the substrate, a second insulator mounted on the substrate adjacent to the first insulator, and a metal overlay mounted on the emitter electrode so that the emitter electrode protrudes beyond the edge of the metal overlay, said first single crystal comprising a thin film of gallium arsenide mounted on the second insulator and the emitter electrode being formed from another gallium arsenide single crystal, mounted on the first insulator.

8. A method for producing a field emission device comprising the steps of providing a substrate; forming an emitter electrode on the substrate; and forming a gate electrode on the substrate adjacent to the emitter electrode from a single crystal, wherein there is a gap between the emitter electrode and the gate electrode.

9. A method for producing a field emission device comprising the steps of providing a substrate; forming a single crystal thin film on the substrate; and forming a gate electrode and an emitter electrode from the thin film so that there is a gap between the gate electrode and the emitter electrode.

10. A method for producing a field emission device, comprising the steps of providing a substrate; forming a first single crystal thin film on the substrate; forming a second single crystal thin film on the substrate; forming a gate electrode from the first thin film; and forming an emitter electrode from the second thin film so that there is a gap between the gate electrode and the emitter electrode.

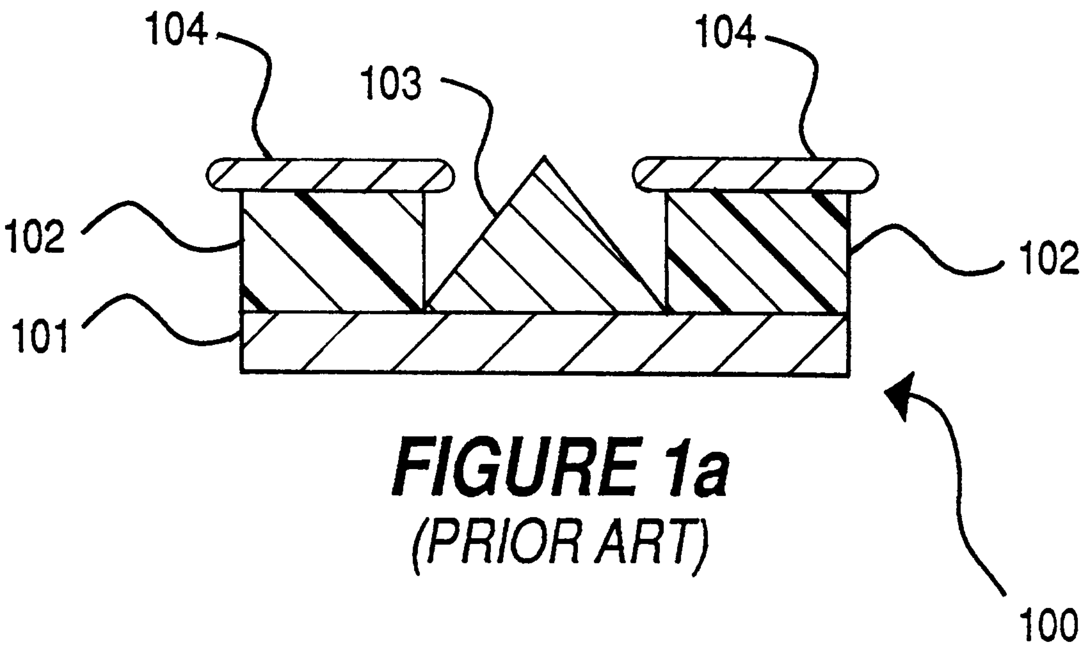

FIGURE 1a
(PRIOR ART)

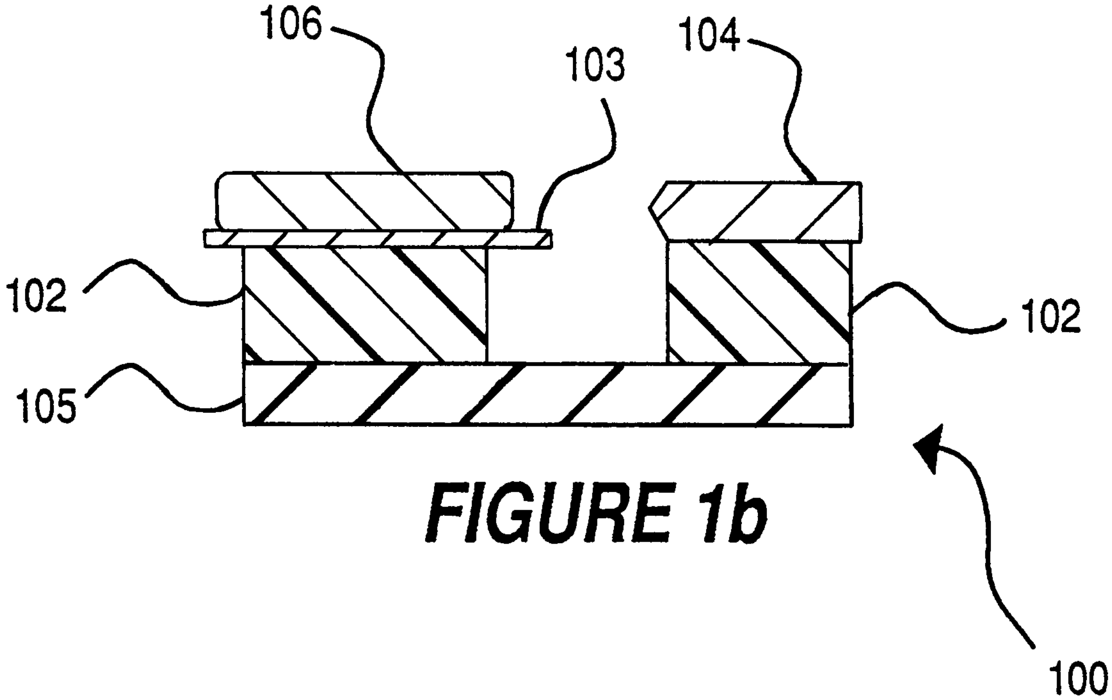

FIGURE 1b

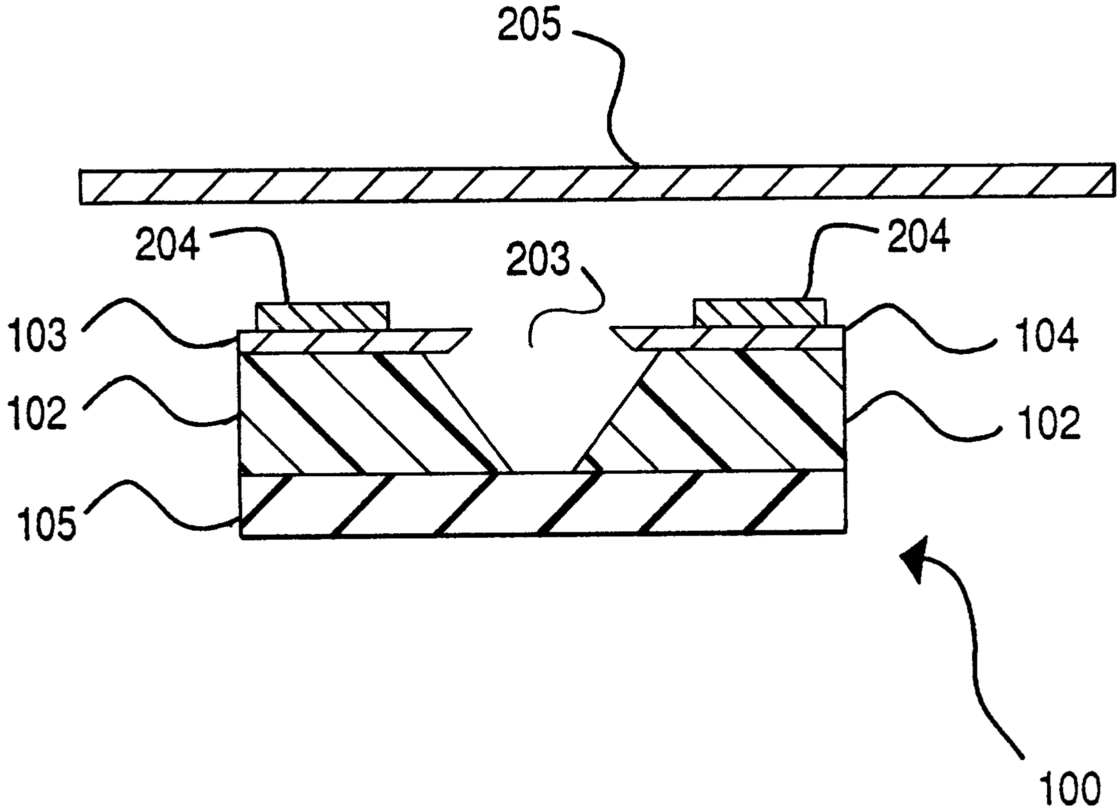

FIGURE 2

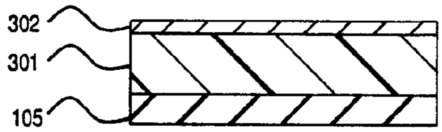

FIGURE 3a

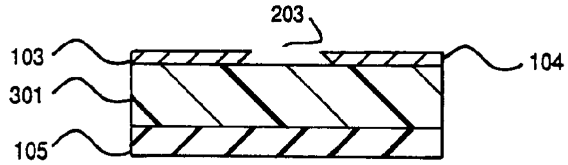

FIGURE 3d

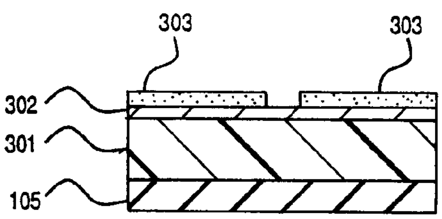

FIGURE 3b

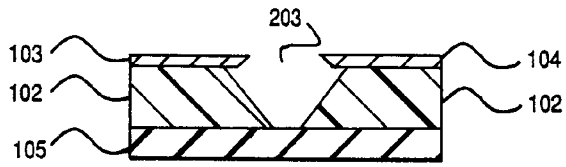

FIGURE 3e

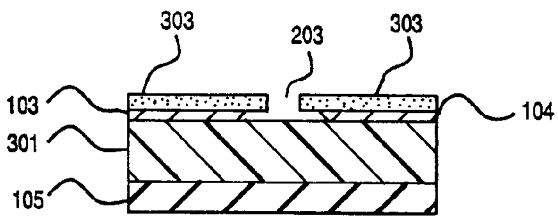

FIGURE 3c

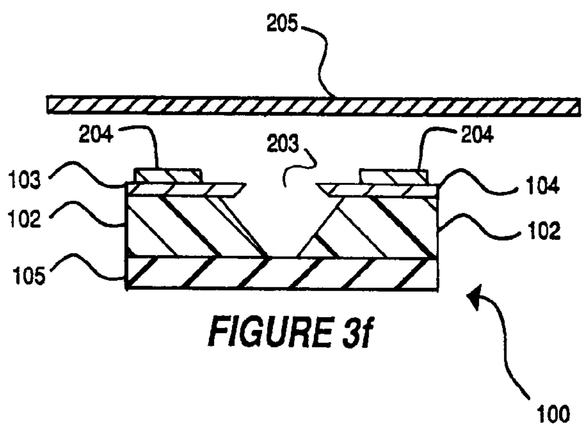

FIGURE 3f

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 5424

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X A	WO-A-92 004 732 (MOTOROLA) 19 March 1992 * page 1, line 16 - page 2, line 5 * * page 4, line 16 - page 5, line 31 * * page 6, line 16 - page 7, line 2; figures 1A-1L,3A-3D * * figure 4B * ---	1 2,3,8-10	H01J1/30 H01J9/02
A	EP-A-0 444 670 (MATSUSHITA) 4 September 1991 * column 4, line 3 - line 53; figures 2,5 * ---	1,8-10	
P,X	US-A-5 214 347 (H.GRAY) 25 May 1993 * column 4, line 39 - line 53 * * column 4, line 63 - column 5, line 22 * * column 5, line 32 - line 49 * * column 6, line 6 - line 14 * * column 6, line 27 - line 34 * * column 7, line 12 - line 24; figures 2,5 * -----	1	TECHNICAL FIELDS SEARCHED (Int. Cl.5) H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 OCTOBER 1993	ROWLES K.E.G.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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