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2 ELECTRON FIELD EMISSION

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4 This invention generally relates to cold cathode field
5 emission.

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7 FIELD OF INVENTION

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9 Although the current world market for flat panel displays is
10 dominated by liquid crystal displays, this may change with the
11 advent of field emission displays. Field emission displays can use
12 an array of cold cathodes as a source of electrons to impinge on an
13 anode applied to a phosphor-coated substrate.

14 Traditional cold cathodes either use high electric fields
15 produced by sharp tips or a cesium-treated semiconductor surface as
16 a high current source of electrons. The problem with these types
17 of cathodes is that they require ultra high vacuum conditions, pose
18 difficulties in fabrication and tend to degrade with time.

19 Diamond, because of its negative electron affinity and
20 chemical and mechanical properties, has been proposed as an
21 alternative to metals as a cold cathode material.

22 Preliminary reports in the technical literature indicate that
23 diamond cold cathodes can operate at pressures of about 10^{-6} torr
24 or less without any degradation in emission current over time. The
25 literature reports also reflect that current designs for diamond
26 cold cathodes fall within the categories of polycrystalline boron-

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1 doped diamond films grown on silicon substrates and boron-doped
2 diamond films fabricated with pyramidal-shaped or cone-shaped tips
3 to enhance field emission of electrons.

4 USP 5,341,063 to Kumar discloses a field emitter with diamond
5 emission tips. The Kumar field emitter comprises a conductive
6 metal and diamond emission tips in ohmic contact with and
7 protruding above the metal. The Kumar emitter is fabricated by
8 coating a substrate with an insulating diamond film having a top
9 surface with spikes and valleys, depositing a conductive metal on
10 the film, etching the metal to expose the spikes, and annealing the
11 emitter to provide ohmic contact between the diamond film and the
12 metal. The Kumar patent discloses that in the diamond literature,
13 tip radii as small as 100 nanometers have been reported.

14
15 SUMMARY OF INVENTION
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17 An object of this invention is to reduce cost of fabricating
18 a diamond field emitter array.

19 Another object of this invention is a field emitter array
20 which is fabricated at a temperature that is not damaging to
21 components of such an array.

22 Another object of this invention is to make a field emitter
23 array from diamond powder using a simple process.

24 These and other objects of this invention are attained by an
25 electron field emitter composed of a substrate and diamond powder

1 particles secured to the substrate. The emitter is fabricated by
2 depositing a diamond powder on a substrate and affixing the diamond
3 powder particles to the substrate.

4
5 DETAILED DESCRIPTION OF INVENTION
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7 Fabrication of the diamond field emitter array of this
8 invention involves depositing diamond powder on a substrate. The
9 powder is affixed to the substrate so that particles of the diamond
10 powder are physically attached to the substrate and are not
11 separated therefrom when the emitter is mechanically jolted or
12 turned over. The powder can be ion implanted before or after the
13 powder particles are secured to the substrate to modify the
14 conductivity of electrons. The fabrication product is an electron
15 diamond powder field emitter array wherein the cathodes are tips of
16 the diamond powder particles. Under the influence of an applied
17 electric field, these tips emit electrons which pass through vacuum
18 and impinge on a phosphor screen disposed above the powder. The
19 impingement of the electrons on the phosphor screen illuminates the
20 phosphors. It is estimated that the field emitter of this
21 invention can have on the order of 10,000 diamond tips/cm². The
22 distance between the tips is less than 1 micron.

23 A substrate is selected depending on requirements,
24 application, availability, and possibly other factors. For
25 purposes herein, a substrate serves as a support surface for the

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1 diamond powder particles that are deposited thereon and conducts
2 electrons when an electric field is applied thereto. The substrate
3 can be a metal or a semiconducting material. The substrate must
4 conduct electrons at least to the extent of a semiconductor. A
5 substrate can be of an insulating material initially in which case,
6 it is ion implanted to render it electron conducting or coated with
7 another material to enhance conductivity of electrons from a
8 biasing source and through the powder particles. It is believed
9 that electron emission appears to be enhanced by rendering the
10 substrate more conductive to electrons. Specific materials suitable
11 for a substrate include silicon, gallium arsenide, tungsten,
12 tantalum, titanium and molybdenum. Dimensions of a typical
13 substrate are on the order of four square millimeters in surface
14 area with a thickness on the order of one-half millimeter, although
15 the dimensions can vary widely to meet requirements of a particular
16 application. Typically, thickness of a substrate is 1 to 500
17 microns, more typically 10 to 300 microns, although substrates of
18 other thicknesses can be used.

19 The top surface to which the diamond particles are affixed is
20 preferably flat. Typically, deviation of the top surface of a
21 substrate from flat for purposes herein, will not be greater than
22 the average diameter of the diamond particles deposited on the
23 substrate.

24 The powder particles deposited on the top surface of the
25 substrate should be deposited uniformly to form one layer of the

1 particles on the substrate. The uniform deposition of the
2 particles on a substrate ensures a uniform discharge of electrons
3 from the particles. The electrons energize the pixels on the
4 phosphor screen disposed directly above which is picked up and
5 transmitted by a receiver and delivered to an eye.

6 Suitable diamond powder can come from natural or synthetic
7 diamonds. Suitable powder particle size varies from about 10
8 nanometers to about 10 microns with an average particle size or
9 diameter of less than about 1000 nanometers, although powders with
10 lower or higher particle sizes are suitable. One typical natural
11 diamond powder suitable herein has particle size varying from about
12 500 nanometers down to about 50 nanometers with an average particle
13 diameter of about 150 nanometers. In this class of powders, 95% of
14 the powder particles have diameters of less than about 0.30 micron
15 or 300 nanometers and 10% of the powder particles have diameters of
16 less than about 0.70 micron or 700 nanometers. Presently,
17 commercially available diamond powders typically provide tips
18 having a tip apex radius of about 50 nanometers or less. It is
19 believed that the sharper the powder particle tips, the easier it
20 is for electrons to escape.

21 The diamond powder, in unconsolidated or non-agglomerated form
22 with discrete particles, can be applied to a substrate at room
23 temperature in any conceivable manner that results in physical
24 attachment of the powder particles to the substrate. It is
25 necessary that attachment of a diamond powder particle establishes

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1 an electrical contact between the diamond particle and the
2 substrate. The powder particles can be attached to the substrate
3 by the use of an appropriate bonding agent or by scratching the
4 powder particles against the substrate in order to embed the
5 particles in the substrate. The attachment of the particle to the
6 substrate should be such that the particle is not dislodged when
7 the substrate is jolted or turned on its side.

8 Commercially available diamond powder with an appropriate
9 particle size can be used herein. Finer diamond powder may become
10 readily available in the future, and should provide even better
11 results in terms of facility of electron escape from the powder
12 particle tips. The powder used for purposes herein can be ion-
13 implanted to provide electrical conductivity therethrough and to
14 enhance electron tunneling through the tips of the powder
15 particles.

16 One way to attach the diamond powder particles to the
17 substrate is to provide ohmic contact therebetween. Ohmic contact
18 between the particles and a metal substrate can be provided by
19 annealing the field emitter consisting of the substrate with the
20 particles thereon heated to an elevated temperature. The ohmic
21 contact so formed appears to be a thin layer of a carbide of
22 diamond and the substrate metal.

23 The diamond powder disposed on a substrate can be ion
24 implanted in a conventional manner with a dopant that can enhance
25 electrical conductivity. Ion implantation of diamond powder is

1 typically done before the annealing step. If a diamond powder
2 which has been previously ion implanted is used, ion implantation
3 of such a powder may be dispensed with.

4 In operation, a field emitter consisting of a metal substrate
5 with diamond powder particles on its top planar surface uniformly
6 distributed and affixed thereto. The emitter is disposed
7 horizontally and an anode is disposed thereover, spaced from the
8 emitter but in close, parallel proximity thereto. The anode is
9 typically a metal coating disposed on a glass plate with a phosphor
10 layer interposed therebetween, with a thin metal coating facing the
11 emitter. A voltage imposed between the anode and the emitter,
12 which functions as the cathode, facilitates conduction of electrons
13 through the substrate and through the tips of the diamond powder
14 particles. As the electrons tunnel through the tips of the diamond
15 particles under the influence of an electrical field, they are
16 emitted from the tips and travel through a substantial vacuum
17 towards the anode. Although the diamond powder disposed on a
18 substrate is not an orderly array in the sense of prior art field
19 emitters characterized by CVD deposited diamond films, the
20 electrons emitted by the field emitter of this invention impinge on
21 the phosphor coating and energize the pixels thereon. The image of
22 the energized pixels is shown visually.

23 For a field emitter of this invention to emit electrons, a
24 minimum voltage of about 5 volts per micron of gap width between
25 the cathode and anode is typically used. This minimum voltage can

1 also depend on parameters such as particle size of the diamond
2 powder, material of the substrate material of the anode, gap
3 between the anode and cathode, and other parameters. A maximum
4 voltage of about 50 volts per micron of the gap separation can be
5 tolerated. If less than about 10 volts per micron is impressed, the
6 electrons may lack sufficient energy to tunnel through the tip and
7 then travel through the vacuum to the anode. If, however, the
8 impressed voltage of about 50 volts per micron is exceeded, then
9 arching would be expected. Typically, however, the biasing voltage
10 will be in the approximate range of 10 to 50 volts per micron of
11 the gap width.

12
13 EXAMPLE
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15 This example demonstrates the use of a natural diamond powder
16 field emitter.

17 The field emitter of this example was made by embedding
18 diamond powder in a flat rectangular piece of molybdenum which
19 functioned as a substrate. The powder was commercially obtained
20 from Norton Materials of Saint-Gobain Industrial Ceramics. The
21 powder had a particle distribution in the range of 0.5 to 0.05
22 micron with an average particle diameter of 0.15 micron or 150
23 nanometers. Average tip radius of the tip apex was about 20
24 nanometers. The molybdenum substrate was a rectangular sheet of
25 molybdenum measuring 1 centimeter by 1 centimeter with a constant

1 thickness of about 0.2 millimeters.

2 The powder was affixed to the substrate by means of a Q-tip
3 applicator by rubbing or scratching the powder until the powder
4 particles adhered to the substrate. The operation with the
5 applicator was conducted over a period of about 3 minutes and
6 resulted in a diamond powder field emitter with about 10,000 tips
7 or peaks per square centimeter of the substrate.

8 To test the efficacy of the field emitter, it was placed in a
9 vacuum of 10^{-8} torr. A tantalum probe in the form of a wire with a
10 diameter of 0.25 millimeter was disposed thereover with a gap
11 between the probe and the emitter of 25 microns, and a voltage of
12 about 3,000 volts was impressed between the substrate and the
13 probe. The biasing of the assembly was accomplished by
14 electrically connecting the probe, which functioned as the cathode,
15 to the substrate, which functioned as part of the cathode, by way
16 of a electrical source which supplied the 3,000 volts. The diamond
17 tips of the powder particles functioned as the cathode. This
18 assembly produced a current of 10^{-5} amperes (10 microamperes)
19 between the anode and the cathode. Normalizing the fields and
20 current densities, the current of 10^{-5} amperes compared favorably
21 with what was reported in the technical literature as being
22 adequate for a field emitter.

23 An identical molybdenum substrate, but devoid of the diamond
24 powder, demonstrated no field emission when placed in the identical
25 assembly described above.

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ABSTRACT

In a system containing an electron field emitter array characterized by applying diamond powder to a substrate and affixing the powder thereto, the diamond powder being composed of particles having sharp tips which are adapted to emit electrons in a vacuum and in an electric field, which electrons impact a phosphor layer disposed on an anode spaced above the tips of the diamond powder particles.