Claims

1. A single crystal CVD synthetic diamond material comprising:

a total as-grown nitrogen concentration equal to or greater than 5 ppm, and

a uniform distribution of defects, wherein said uniform distribution of defects is defined by one or more of the following characteristics:

(i) the total nitrogen concentration, when mapped by secondary ion mass spectrometry (SIMS) over an area equal to or greater than 50 x 50 μm using an analysis area of 10 μm or less, possesses a point-to-point variation of less than 30% of an average total nitrogen concentration value, or when mapped by SIMS over an area equal to or greater than 200 x 200 μm using an analysis area of 60 μm or less, possesses a point-to-point variation of less than 30% of an average total nitrogen concentration value;

(ii) an as-grown nitrogen-vacancy defect (NV) concentration equal to or greater than 50 ppb as measured using 77K UV-visible absorption measurements, wherein the nitrogen-vacancy defects are uniformly distributed through the synthetic single crystal CVD diamond material such that, when excited using a 514 nm laser excitation source of spot size equal to or less than 10 μm at room temperature using a 50 mW continuous wave laser, and mapped over an area equal to or greater than 50 x 50 μm with a data interval less than 10 μm, there is a low point-to-point variation wherein the intensity area ratio of nitrogen vacancy photoluminescence peaks between regions of high photoluminescent intensity and regions of low photolominescent intensity is <2x for either the 575 nm photoluminescent peak (NV^0) or the 637 nm photoluminescent peak (NV^-);

(iii) a variation in Raman intensity such that, when excited using a 514 nm laser excitation source (resulting in a Raman peak at 552.4 nm) of spot size equal to or less than 10 μm at room temperature using a 50 mW continuous wave laser, and mapped over an area equal to or greater than 50 x 50 μm with a data interval less than 10 μm, there is a low point-to-point variation wherein the ratio of Raman peak areas between regions of low Raman intensity and high Raman intensity is <1.25x;

(iv) an as-grown nitrogen-vacancy defect (NV) concentration equal to or greater than 50 ppb as measured using 77K UV-visible absorption measurements,

wherein, when excited using a 514 nm excitation source of spot size equal to or less than 10 μm at 77K using a 50 mW continuous wave laser, gives an intensity at 575 nm corresponding to NV^0 greater than 120 times a Raman intensity at 552.4 nm, and/or an intensity at 637 nm corresponding to NV^- greater than 200 times the Raman intensity at 552.4 nm;

(v) a single substitutional nitrogen defect (N_s) concentration equal to or greater than 5 ppm, wherein the single substitutional nitrogen defects are uniformly distributed through the synthetic single crystal CVD diamond material such that by using a 1344 cm^{-1} infrared absorption feature and sampling an area greater than an area of 0.5 mm^2, the variation is lower than 80%, as deduced by dividing the standard deviation by the mean value;

(vi) a variation in red luminescence intensity, as defined by a standard deviation divided by a mean value, is less than 15%;

(vii) a mean standard deviation in neutral single substitutional nitrogen concentration of less than 80%; and

(viii) a colour intensity as measured using a histogram from a microscopy image with a mean gray value of greater than 50, wherein the colour intensity is uniform through the single crystal CVD synthetic diamond material such that the variation in gray colour, as characterised by the gray value standard deviation divided by the gray value mean, is less than 40%.

2. A single crystal CVD synthetic diamond material according to claim 1, wherein the single crystal CVD synthetic diamond material comprises two, three, four, five, six, seven or all eight of said characteristics.

3. A single crystal CVD synthetic diamond material according to claim 1 or 2, wherein the total nitrogen concentration, when mapped by secondary ion mass spectrometry (SIMS) over an area equal to or greater than 50 x 50 μm with an analysis area defined as 10 μm or less, possesses a point-to-point variation of less than 25%, 20%, 15%, 10%, 5%, 3%, or 1% of an average nitrogen concentration value.

4. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the luminescence from the nitrogen-vacancy defects, when mapped

over an area equal to or greater than 50 x 50 μm with an analysis area defined as 10 μm or less, possesses a point-to-point variation such that the intensity ratio between regions of high PL intensity and regions of low PL intensity is less than 1.8, 1.6, 1.4, or 1.2.

5. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the NV^0 luminescence at 575 nm is greater than 140, 160, or 180 times the Raman intensity at 552.4 nm, and/or the NV^- luminescence at 637 nm is greater than 220, 240, or 260 times the Raman intensity at 552.4 nm;

6. A single crystal CVD synthetic diamond material according to any preceding claim, the single substitutional nitrogen defects are uniformly distributed through the synthetic single crystal CVD diamond material such that by using the 1344 cm^{-1} infrared absorption feature from the single substitutional nitrogen defects and sampling an area greater than an area of 0.5 mm^2 the variation is lower than 60%, 40%, 20%, 10% as deduced by dividing the standard deviation by the mean..

7. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the variation in red luminescence is less than 10%, 8%, 6%, or 4%.

8. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the mean standard deviation in neutral single substitutional nitrogen concentration is less than 60%, 40%, 20%, or 10%.

9. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the colour intensity, when imaged over volume equal to or greater than 200 x 200 x 200 μm, possesses a point-to-point variation of less than 30%, 20%, 10%, or 5% of an average colour intensity, as defined by the gray value standard deviation divided by the gray value mean.

10. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the total nitrogen concentration is equal to or greater than 7 ppm, 10

ppm, 15 ppm, 20 ppm, 30 ppm, 50 ppm, 75 ppm, 100 ppm, 150 ppm, 200 ppm, or 300 ppm.

11. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single substitutional nitrogen defect (N_s) concentration is equal to or greater than 7 ppm, 10 ppm, 15 ppm, 20 ppm, 30 ppm, 50 ppm, 75 ppm, 100 ppm, 150 ppm, 200 ppm, or 300 ppm.

12. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the as-grown nitrogen-vacancy defect (NV^-) concentration is equal to or greater than 120 ppb, 140 ppb, 160 ppb, 180 ppb, 200 ppb, 250 ppb, 300 ppb, 400 ppb, 500 ppb, 1000 ppb, or 5000 ppb.

13. A single crystal CVD synthetic diamond material according to any preceding claim, having a concentration of silicon equal to or less than $1x10^{15}$ atoms cm^{-3}.

14. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material has a longest dimensions equal to or greater than 200 μm, 500 μm, 1 mm, 1.5 mm, 2.0 mm, 3.0 mm, or 5.0 mm.

15. A single crystal CVD synthetic diamond material according to any preceding claim, having a volume equal to or greater than 0.01 mm^3, 0.05 mm^3, 0.1 mm^3, 0.5 mm^3, 1.0 mm^3, 3.0 mm^3, 6.0 mm^3, 9.0 mm^3, or 15.0 mm^3 though which said one or more characteristics hold true.

16. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material is in the form of a layer having a thickness less than 200 μm, 100 μm, 50 μm, 20 μm, 10 μm, 5 μm, 2 μm, or 1 μm.

17. A single crystal CVD synthetic diamond material according to any one of claims 1 to 15, wherein the single crystal CVD synthetic diamond material is in the

form of a layer having a thickness greater than 200 μm, 500 μm, 1 mm, 1.5 mm, 2.0 mm, 3.0 mm, or 5.0 mm.

18. A single crystal CVD synthetic diamond material according to any preceding claim, having a dislocation bundle density equal to or less than: 10^6 dislocations cm^{-2}; 10^4 dislocations cm^{-2}; 3 x 10^3 dislocations cm^{-2}; 10^3 dislocations cm^{-2}; 10^2 dislocations cm^{-2}; or 10 dislocations cm^{-2}.

19. A single crystal CVD synthetic diamond material according to any preceding claim, having a birefringence equal to or less than 5 x 10^{-5}, 1 x 10^{-5}, 5 x10^{-6}, or 1 x10^{-6};

20. A single crystal CVD synthetic diamond material according to any preceding claim, which has been annealed and/or irradiated.

21. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material has one or more of the following colours: pink, yellow, green, orange, red, purple.

22. A method of fabricating a single crystal CVD diamond material according to any preceding claim, the method comprising:

forming a CVD synthesis atmosphere comprising hydrogen, a carbon source gas, a nitrogen source gas, and optionally an oxygen source gas, wherein the CVD synthesis atmosphere comprises an atomic concentration of nitrogen relative to a total gas composition in a range 0.1% to 3%;

growing single crystal CVD diamond material on a single crystal diamond substrate mounted on a support substrate; and

controlling the temperature of the support substrate such that temperature variations across the support substrate at any given point in the growth process are less than 50°C of a target temperature value, temperature variations throughout the growth run are less then 50°C of the target temperature value, and the target temperature value lies in a range 1000°C to 1400°C,

wherein the CVD synthesis atmosphere comprises at least one of:

an atomic concentration of carbon relative to the total gas composition in a range 0.1% to 2.0%; and

an atomic concentration of oxygen relative to the total gas composition in a range 5% to 40%.

23. A method according to claim 22, wherein the atomic concentration of nitrogen relative to the total gas composition is in a range 0.1% to 2%, 0.1% to 1%, or 0.2% to 0.8%.

24. A method according to claim 22 or 23, wherein the atomic concentration of carbon relative to the total gas composition is in a range 0.3% to 1.7%, 0.5% to 1.5%, 0.7% to 1.3%, or 0.8% to 1.2%.

25. A method according to any one of claims 22 to 24, wherein no oxygen source gas is added to the CVD synthesis atmosphere.

26. A method according to any one of claims 22 to 24, wherein oxygen source gas is added to the CVD synthesis atmosphere such that the CVD synthesis atmosphere comprises an atomic concentration of oxygen in a range 5% to 40%, 10% to 30%, 10% to 25%, or 15% to 20%.

27. A method according to any one of claims 22 to 26, wherein the single crystal diamond substrate is mounted to the support substrate by a braze alloy having a melting point equal to or greater than 1000°C, 1100°C, 1200°C, 1300°C, or 1400°C.

28. A method according to any one of claims 22 to 27, wherein the support substrate comprises a refractory metal.

29. A method according to any one of claims 22 to 28, wherein the temperature variations across the support substrate are less than 40°C, 30°C, 20°C, 10°C, or 5°C.

30. A method according to any one of claims 22 to 29, wherein temperature variations across the single crystal diamond substrate are less than 50°C, 40°C, 30°C, 20°C, 10°C,or 5°C.

31. A method according to any one of claims 22 to 30, wherein the single crystal diamond substrate is mounted to the support substrate by a braze alloy having a melting point less than the target temperature for growing single crystal CVD diamond material on the single crystal diamond substrate such that the braze alloy is in a liquid state during growth of the single crystal CVD diamond material.

Claims

1. A single crystal CVD synthetic diamond material comprising:

a total as-grown nitrogen concentration equal to or greater than 5 ppm, and

a uniform distribution of defects, wherein said uniform distribution of defects is defined by one or more of the following characteristics:

(i) the total nitrogen concentration, when mapped by secondary ion mass spectrometry (SIMS) over an area equal to or greater than 50 x 50 μm using an analysis area of 10 μm or less, possesses a point-to-point variation of less than 30% of an average total nitrogen concentration value, or when mapped by SIMS over an area equal to or greater than 200 x 200 μm using an analysis area of 60 μm or less, possesses a point-to-point variation of less than 30% of an average total nitrogen concentration value;

(ii) an as-grown nitrogen-vacancy defect (NV) concentration equal to or greater than 50 ppb as measured using 77K UV-visible absorption measurements, wherein the nitrogen-vacancy defects are uniformly distributed through the synthetic single crystal CVD diamond material such that, when excited using a 514 nm laser excitation source of spot size equal to or less than 10 μm at room temperature using a 50 mW continuous wave laser, and mapped over an area equal to or greater than 50 x 50 μm with a data interval less than 10 μm, there is a low point-to-point variation wherein the intensity area ratio of nitrogen vacancy photoluminescence peaks between regions of high photoluminescent intensity and regions of low photolominescent intensity is <2x for either the 575 nm photoluminescent peak (NV^0) or the 637 nm photoluminescent peak (NV^-);

(iii) a variation in Raman intensity such that, when excited using a 514 nm laser excitation source (resulting in a Raman peak at 552.4 nm) of spot size equal to or less than 10 μm at room temperature using a 50 mW continuous wave laser, and mapped over an area equal to or greater than 50 x 50 μm with a data interval less than 10 μm, there is a low point-to-point variation wherein the ratio of Raman peak areas between regions of low Raman intensity and high Raman intensity is <1.25x;

(iv) an as-grown nitrogen-vacancy defect (NV) concentration equal to or greater than 50 ppb as measured using 77K UV-visible absorption measurements, wherein, when excited using a 514 nm excitation source of spot size equal to or less than 10 μm at 77K using a 50 mW continuous wave

laser, gives an intensity at 575 nm corresponding to NV^0 greater than 120 times a Raman intensity at 552.4 nm, and/or an intensity at 637 nm corresponding to NV^- greater than 200 times the Raman intensity at 552.4 nm;

(v) a single substitutional nitrogen defect (N_s) concentration equal to or greater than 5 ppm, wherein the single substitutional nitrogen defects are uniformly distributed through the synthetic single crystal CVD diamond material such that by using a 1344 cm^{-1} infrared absorption feature and sampling an area greater than an area of 0.5 mm^2, the variation is lower than 80%, as deduced by dividing the standard deviation by the mean value;

(vi) a variation in red luminescence intensity, as defined by a standard deviation divided by a mean value, is less than 15%;

(vii) a mean standard deviation in neutral single substitutional nitrogen concentration of less than 80%; and

(viii) a colour intensity as measured using a histogram from a microscopy image with a mean gray value of greater than 50, wherein the colour intensity is uniform through the single crystal CVD synthetic diamond material such that the variation in gray colour, as characterised by the gray value standard deviation divided by the gray value mean, is less than 40%.

2. A single crystal CVD synthetic diamond material according to claim 1, wherein the single crystal CVD synthetic diamond material comprises two, three, four, five, six, seven or all eight of said characteristics.

3. A single crystal CVD synthetic diamond material according to claim 1 or 2, wherein the total nitrogen concentration, when mapped by secondary ion mass spectrometry (SIMS) over an area equal to or greater than 50 x 50 μm with an analysis area defined as 10 μm or less, possesses a point-to-point variation of less than 25%, 20%, 15%, 10%, 5%, 3%, or 1% of an average nitrogen concentration value.

4. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the luminescence from the nitrogen-vacancy defects, when mapped over an area equal to or greater

than 50 x 50 μm with an analysis area defined as 10 μm or less, possesses a point-to-point variation such that the intensity ratio between regions of high PL intensity and regions of low PL intensity is less than 1.8, 1.6, 1.4, or 1.2.

5. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the NV^0 luminescence at 575 nm is greater than 140, 160, or 180 times the Raman intensity at 552.4 nm, and/or the NV^- luminescence at 637 nm is greater than 220, 240, or 260 times the Raman intensity at 552.4 nm;

6. A single crystal CVD synthetic diamond material according to any preceding claim, the single substitutional nitrogen defects are uniformly distributed through the synthetic single crystal CVD diamond material such that by using the 1344 cm^{-1} infrared absorption feature from the single substitutional nitrogen defects and sampling an area greater than an area of 0.5 mm^2 the variation is lower than 60%, 40%, 20%, 10% as deduced by dividing the standard deviation by the mean..

7. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the variation in red luminescence is less than 10%, 8%, 6%, or 4%.

8. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the mean standard deviation in neutral single substitutional nitrogen concentration is less than 60%, 40%, 20%, or 10%.

9. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the colour intensity, when imaged over volume equal to or greater than 200 x 200 x 200 μm, possesses a point-to-point variation of less than 30%, 20%, 10%, or 5% of an average colour intensity, as defined by the gray value standard deviation divided by the gray value mean.

10. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the total nitrogen concentration is equal to or greater than 7 ppm, 10 ppm, 15 ppm, 20 ppm, 30 ppm, 50 ppm, 75 ppm, 100 ppm, 150 ppm, 200 ppm, or 300 ppm.

11. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single substitutional nitrogen defect (N_s) concentration is equal to or greater than 7 ppm, 10 ppm, 15 ppm, 20 ppm, 30 ppm, 50 ppm, 75 ppm, 100 ppm, 150 ppm, 200 ppm, or 300 ppm.

12. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the as-grown nitrogen-vacancy defect (NV^-) concentration is equal to or greater than 120 ppb, 140 ppb, 160 ppb, 180 ppb, 200 ppb, 250 ppb, 300 ppb, 400 ppb, 500 ppb, 1000 ppb, or 5000 ppb.

13. A single crystal CVD synthetic diamond material according to any preceding claim, having a concentration of silicon equal to or less than $1x10^{15}$ atoms cm^{-3}.

14. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material has a longest dimensions equal to or greater than 200 μm, 500 μm, 1 mm, 1.5 mm, 2.0 mm, 3.0 mm, or 5.0 mm.

15. A single crystal CVD synthetic diamond material according to any preceding claim, having a volume equal to or greater than 0.01 mm^3, 0.05 mm^3, 0.1 mm^3, 0.5 mm^3, 1.0 mm^3, 3.0 mm^3, 6.0 mm^3, 9.0 mm^3, or 15.0 mm^3 though which said one or more characteristics hold true.

16. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material is in the form of a layer having a thickness less than 200 μm, 100 μm, 50 μm, 20 μm, 10 μm, 5 μm, 2 μm, or 1 μm.

17. A single crystal CVD synthetic diamond material according to any one of claims 1 to 15, wherein the single crystal CVD synthetic diamond material is in the form of a layer having a thickness greater than 200 μm, 500 μm, 1 mm, 1.5 mm, 2.0 mm, 3.0 mm, or 5.0 mm.

18. A single crystal CVD synthetic diamond material according to any preceding claim, having a dislocation bundle density equal to or less than: 10^6 dislocations cm^{-2}; 10^4 dislocations cm^{-2}; 3×10^3 dislocations cm^{-2}; 10^3 dislocations cm^{-2}; 10^2 dislocations cm^{-2}; or 10 dislocations cm^{-2}.

19. A single crystal CVD synthetic diamond material according to any preceding claim, having a birefringence equal to or less than 5×10^{-5}, 1×10^{-5}, 5×10^{-6}, or 1×10^{-6}.

20. A single crystal CVD synthetic diamond material according to any preceding claim, which has been annealed and/or irradiated.

21. A single crystal CVD synthetic diamond material according to any preceding claim, wherein the single crystal CVD synthetic diamond material has one or more of the following colours: pink, yellow, green, orange, red, purple.