METHOD FOR DEPOSITING HIGHLY DOPED ALUMINUM NITRIDE PIEZOELECTRIC MATERIAL

FIELD

[0001] The invention relates to a method for manufacturing a doped wurtzite aluminum nitride piezoelectric thin film material, which method comprises the steps of: providing a deposition device, such as a pulsed lased deposition device or a physical vapor deposition device, with a target and a substrate, wherein a target material of the target is a doped aluminum nitride composite, wherein a doping element is a rare earth element, preferably scandium; depositing a first layer of the target material on the substrate by operating the deposition device, wherein a kinetic energy of plasma particles being deposited is above a first threshold value; and depositing a second layer of the target material on top of the first layer by operating the deposition device, wherein the kinetic energy of the plasma particles being deposited is below a second threshold value.

[0002] For the invention, the kinetic energy of the plasma particles is defined by the plasma temperature measured in electron volts (eV). The plasma temperature is a common measure of the thermal kinetic energy per particle.

BACKGROUND

[0003] It is known from, for example EP 3340327 in the name of the Applicant, to manufacture a piezoelectric material with a pulsed laser deposition device. From this publication it is also known to apply two or more layers of the target material onto a substrate, while using different process parameters for each of the layers.

[0004] EP 3340327 teaches to use a low deposition rate for the first layer and to use a high deposition rate for the second and further layers. This ensures that the second layer has a less erratic crystal structure compared to a piezoelectric material, which has been grown using only the high deposition rate.

[0005] When a doped aluminum nitride composite, in particular scandium aluminum nitride, is used to manufacture a piezoelectric material, it is known that by increasing the scandium concentration, the piezoelectric response also increases. (See: Morito Akiyama et. al. (2009) “Influence of growth temperature and scandium concentration on piezoelectric response of scandium aluminum nitride alloy thin films”. Applied Physics Letters 95, 162107 (2009)).

[0006] However, if the doping concentration is increased to high values (>20% scandium), unwanted features start to appear on the film surface. These features are visible with a

the layer deposited by said plasma particles and wherein the kinetic energy of the plasma particles is above the first threshold value while depositing the first layer by keeping the stress in said first layer lower than -500MPa, preferably lower than -1000MPa.

[0023] In another alternative embodiment of the method according to the invention wherein the kinetic energy of the plasma particles is derived from the stress in the layer deposited by said plasma particles and wherein the kinetic energy of the plasma particles is below the second threshold value while depositing the second layer by keeping the stress in said second layer higher than -500MPa, preferably in the range of -400MPa to + 600MPa.

[0024] In a further embodiment of the method according to the invention the thickness of the first layer of the target material is in the range of 10nm – 50nm (nanometers). The exposure of the wafer or electrode during the deposition of such a thickness of the film at high kinetic energy is sufficient to provide the necessary surface cleaning. Also, such a thickness is sufficient to provide a high quality interface with the second layer and allows for the high concentrations of the doping element, without the chance on phase transition.

[0025] In still a further embodiment of the method according to the invention the concentration of the doping element is at least 20% of the target material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Figures 1A – 1C show the steps of the method according to the invention.

[0027] Figure 2A shows a SEM photograph of the surface of a piezoelectric thin film material using a conventional technique.

[0028] Figure 2B shows a SEM photograph of the surface of a piezoelectric thin film material using the method according to the invention.

[0029] Figure 3 shows a diagram of the piezoelectric response in relation to the concentration of a doping element.

DETAILED DESCRIPTION

[0030] Figure 1A shows schematically a pulsed laser deposition device with a target 1 and a substrate 2. A pulsed laser 3 is directed onto the target 1, such that a plasma plume 4 is generated. In order to deposit the target material over the whole surface of the substrate 2, the laser beam 3 is for example scanned over the target 1, while the substrate 2 is rotated, or the substrate 2 is moved linear in two dimensions such that the plasma plume 4 can cover the whole surface of the substrate 2.

CLAIMS:

1. A method for manufacturing a doped wurtzite aluminum nitride piezoelectric thin film material, which method comprises the steps of:

providing a deposition device, such as a pulsed lased deposition device or a physical vapor deposition device, with a target and a substrate, wherein a target material of the target is a doped aluminum nitride composite, wherein a doping element is a rare earth element, preferably scandium;

depositing a first layer of the target material on the substrate by operating the deposition device, wherein the kinetic energy of the plasma particles being deposited is above a first threshold value;

depositing a second layer of the target material on top of the first layer by operating the deposition device, wherein a kinetic energy of plasma particles being deposited is below a second threshold value, wherein the first threshold value is larger than the second threshold value.

2. The method according to claim 1, wherein the first layer of the target material is deposited onto the substrate without any interim treatment of the substrate.

3. The method according to claim 1 or 2, wherein the first threshold value is more than 90eV, preferably in the range of 100eV – 160eV.

4. The method according to any of the preceding claims, wherein the second threshold value is less than 90eV, preferably in the range of 40eV – 80eV.

5. The method according to any of the preceding claims, wherein the kinetic energy of the plasma particles is derived from a stress in the first layer deposited by said plasma particles.

6. The method according to any of the preceding claims, wherein the kinetic energy of the plasma particles is derived from the stress in the second layer deposited by said plasma particles.

7. The method according to any of the preceding claims, wherein the thickness

of the first layer of the target material is in the range of 10nm – 50nm.

8. The method according to any of the preceding claims, wherein the concentration of the doping element is at least 20% of the target material.

9. The method according to claim any of the preceding claims, wherein the rare earth element is scandium.

10. The method according to claim 5, wherein the kinetic energy of the plasma particles deposited to form the first layer is maintained above the first threshold value while depositing the first layer by keeping the stress in the first layer lower than -1000MPa.

11. The method according to claim 6, wherein the kinetic energy of the plasma particles deposited to form the second layer is maintained below the second threshold value while depositing the second layer by keeping a stress in the second layer in a range of -400MPa to +600MPa.

12. The method according to any of the preceding claims, wherein the deposition device is a pulsed laser deposition device or a physical vapor deposition device.

13. The method according to any of the preceding claims, wherein the first threshold value is in the range of 100eV– 160eV.

14. The method according to any of the preceding claims, wherein the second threshold value is in the range of 40eV – 80eV.

15. A deposition device comprising a pulsed laser, the deposition device being adapted to hold a substrate and a target for depositing a film on the substrate by directing laser energy from the pulsed laser at the target, the deposition device being configured to:

deposit a first layer of doped aluminum nitride on a substrate by directing the laser energy at a doped aluminum nitride target, such that a kinetic energy of plasma particles being deposited to form the first layer of doped aluminum nitride is above a first threshold value; and

deposit a second layer of doped aluminum nitride on top of the first layer of

doped aluminum nitride such that a kinetic energy of plasma particles being deposited to form the second layer of doped aluminum nitride is below a second threshold value,

wherein the first threshold value is larger than the second threshold value.

16. The deposition device according to claim 15, wherein the first threshold value is more than 90eV.

17. The deposition device according to any of claims 15-16, further comprising the doped aluminum nitride target, wherein the doped aluminum nitride target is doped with a rare earth element at a concentration of at least 20 molar % of a total concentration of aluminum and the doping element in the target material.

18. The deposition device according to any of claims 15-17, wherein the rare earth element is scandium.

19. The deposition device according to any of claims 15-18, wherein the deposition device is configured to keep a stress in the first layer lower than -500MPa while depositing the first layer.

20. An article, comprising:

a substrate; and

a piezoelectric thin film on the substrate, the piezoelectric thin film comprising

a first layer of doped aluminum nitride on the substrate, the first layer of doped aluminum nitride having a first stress, and

a second layer of doped aluminum nitride on the first layer of doped aluminum nitride, the second layer of doped aluminum nitride having a second stress that is higher than the first stress of the first layer of doped aluminum nitride.

21. The article of claim 20, wherein the first layer of doped aluminum nitride and the second layer of doped aluminum nitride are a same material.

22. The article of any of claims 20-21, wherein the first layer of doped aluminum nitride and the second layer of doped aluminum nitride are doped with scandium.

23. The article of any of claims 20-22, wherein the piezoelectric thin film is substantially free of inverted domains.

24. The article of any of claims 20-23, wherein the piezoelectric film has a general formula of ScxAl(1-x)N, and wherein x is between 0.35 and 0.5.

25. The article of any of claims 20-24, wherein the first layer of doped aluminum nitride has a thickness of 10nm to 50nm.

26. The article of any of claims 20-25, wherein the second layer of doped aluminum nitride is thicker than the first layer of doped aluminum nitride.