

SPECIFICATION

Magnetron sputtering of ferromagnetic material

5 This invention relates to a method for producing a magnetron sputtered film having the properties of a ferromagnetic material.

There are a number of techniques used in industry for the deposition of thin films. The specific technique selected depends upon the particular application and might include high vacuum evaporation, chemical vapour deposition, plating, or sputtering. Each of these techniques offers some unique advantages. For example, almost any material can be deposited by sputtering, including both metals and insulators. With sputtering, alloys and mixtures can be deposited without fractionation and with the assurance that film composition will remain consistent from run to run. The source material will last for a large number of depositions without replenishment. Also a further advantage of certain modes of sputtering is that the deposition is done at a relatively low temperature so that films can be applied to a number of materials that would be adversely affected by the temperature that might be encountered with other deposition methods.

Two problems associated with classical sputter deposition are the low deposition rate and the poor power efficiency. For the most part, these problems have been overcome by the recent advances in high rate magnetic assisted or magnetron sputtering. With magnetron sputtering, magnets are located behind the cathode target in such a manner as to cause closed magnetic field loops to cut through the cathode. A portion of the magnetic field loop is in front of the front face of the cathode. The combination of magnetic field and electron field causes electrons to spiral in long confined paths giving rise to a very dense plasma immediately adjacent to the face of the target material. This dense plasma facilitates an increased yield of material sputtered from the target.

One limitation of magnetron sputtering, however, is that this technique is not amenable to the deposition of ferromagnetic materials. A target of ferromagnetic material would act as a magnetic shunt and would prevent magnetic field lines from cutting through the target and being located, as required, in front of the target. Therefore, materials such as iron or nickel cannot be magnetron sputtered. The only exception to this is that some limited success has been achieved by using specially fabricated targets in which a thin (say, about 1.6 millimeters) layer of the ferromagnetic material has been plated on a non-ferromagnetic base material. The layer is thin enough so as not to completely shunt the magnetic field. Use of such a target, however, defeats some of the advantages of sputtering. For example, the target is now very expensive and the source lifetime is severely limited because of the reduced amount of source material.

Some of the ferromagnetic materials have very desirable properties which render them valuable in many thin film applications. Nickel, for example, has found wide acceptance in the semiconductor indus-

try. Accordingly, a need has existed for an improved method for the magnetron sputtering of ferromagnetic materials that would preserve the desired nonmagnetic properties of the materials.

70 It is an object of this invention to provide a method and a cathode target for the magnetron sputter deposition of nickel or other ferromagnetic materials which will preserve the desired nonmagnetic properties of the ferromagnetic material.

75 The magnetron sputtering of ferromagnetic materials can be accomplished by using as a target material a properly selected alloy of that material. The alloy selected must have a Curie temperature that is lower than the temperature maintained by the target prior to or during the sputtering process. The alloy selected must also be one that preserves the other desirable properties of the ferromagnetic material itself. Specifically, nickel can be deposited by magnetron sputtering by forming an alloy of nickel with about thirty to thirty-five atomic percent of copper. This alloy has a Curie temperature which is below the normal sputtering temperature, but the alloy still retains the desirable properties of nickel in terms of stiffness, thermal heat transfer, corrosion resistance, and solderability.

Thus, according to one aspect of the invention there is provided a method for producing a magnetron sputtered film having the properties of a ferromagnetic material and which comprises using a cathode target formed of said ferromagnetic material alloyed with a non-ferromagnetic material to lower the Curie temperature of the alloy to less than the temperature maintained by said cathode target during the magnetron sputtering.

100 According to another aspect of the invention there is provided a method for depositing by magnetron sputtering a thin film of material having the non-magnetic properties of a ferromagnetic material and which comprises sputtering from a cathode target formed of said ferromagnetic material alloyed with a non-ferromagnetic material to lower the Curie temperature of the alloy to less than the temperature of said cathode target during the magnetron sputtering.

110 The invention will now be described by way of example only with particular reference to the accompanying drawing wherein:

Figure 1 is a schematic representation of a magnetron sputtering apparatus and

115 *Figure 2* shows the Curie temperature as a function of alloy composition for three different alloys of nickel.

Turning first to *Figure 1*, there is shown in schematic representation an apparatus for depositing materials by the magnetron sputtering technique. The cathode target 10 is fabricated of the material desired to be deposited in a thin film layer on the work piece 12. The anode 14 is generally maintained at electrical ground potential or at a small positive potential, and a field is established between the cathode 10 and the anode 14. Magnets 16 are placed behind the cathode 10 to cause magnetic field lines such as indicated by the line 18. The closed-loop magnetic field lines 18 pass through the cathode 10 such that a portion of the field lines

exist in the space in front of cathode 10. Electrons in front of the cathode will be acted upon by the force of the combined electric and magnetic fields. Such a force constrains the electrons to long spiralling paths immediately adjacent to the front surface of the cathode target 10. It is this electromagnetic confinement of the electrons near the cathode that enhances the plasma and improves the efficiency of the magnetron sputtering apparatus.

If the cathode 10, however, is comprised of a ferromagnetic material, this material shunts the magnetic field. Magnetic field lines will then follow a path through the cathode material as depicted by the dotted line 20. Because no magnetic field lines exist in front of the cathode, there can be no enhanced plasma.

The Curie temperature is defined as that temperature above which spontaneous magnetization vanishes. The Curie temperature separates the disordered paramagnetic phase from the ordered ferromagnetic phase. Stated in another way, at temperatures below a material's Curie temperature, that material is strongly magnetic. At temperatures above the Curie temperature the magnetic properties disappear.

The Curie temperature varies over a wide range for various materials and can be different for alloys than for various materials and can be different for alloys than for any of the constituents of the alloy. By properly forming an alloy of a ferromagnetic material with one or more other elements, the Curie temperature can be reduced to a temperature lower than the desired sputtering temperature. With the lowered Curie temperature, the alloy is non-ferromagnetic at the sputtering temperature, and is therefore amenable to magnetron sputtering.

There are many ferromagnetic materials that can be so alloyed to reduce the Curie temperature in this manner. In accordance with the invention, three specific but nonlimiting examples are herein set forth. Nickel, which is a highly desirable thin film metal for many applications has a Curie temperature of approximately 370°C. It is usually desired to do magnetron sputtering with the target held near room temperature, but at room temperature nickel is ferromagnetic. Figure 2 is a graph showing the curie temperature as a function of alloy composition for three different alloys of nickel. These include alloys of nickel and copper, nickel and tin, and nickel and platinum. In the preferred embodiment of this invention an alloy of nickel with about thirty to thirty-five atomic percent copper is used as a target for magnetron sputtering. That particular alloy has a curie temperature which lies in the range between +20°C. and -40°C. This alloy is very nickel-like in all of its nonmagnetic properties, and therefore finds use, for example, in multi-metal innerconnection schemes on semiconductor devices. The alloy adheres to both silicon and silicon dioxide better than pure copper alone. The nickel-copper alloy also has good solderability; that is, the alloy is easily wet by the solder, but does not dissolve in the solder. Like nickel, the alloy is also a relatively poor thermal conductor. In like manner, an alloy of nickel with about forty atomic percent platinum or an alloy of

nickel with about ten atomic percent tin can be readily deposited by the magnetron sputtering technique and yet both of these alloys retain their nickel-like properties.

CLAIMS

1. A method for producing a magnetron sputtered film having the properties of a ferromagnetic material and which comprises using a cathode target formed of said ferromagnetic material alloyed with a non-ferromagnetic material to lower the Curie temperature of the alloy to less than the temperature maintained by said cathode target during the magnetron sputtering.
2. A method for depositing by magnetron sputtering a thin film of material having the non-magnetic properties of a ferromagnetic material and which comprises sputtering from a cathode target formed of said ferromagnetic material alloyed with a non-ferromagnetic material to lower the Curie temperature of the alloy to less than the temperature of said cathode target during the magnetron sputtering.
3. A method as claimed in claim 2 wherein said ferromagnetic material is nickel.
4. A method as claimed in claim 3 wherein said non-ferromagnetic material is copper.
5. A method as claimed in claim 4 wherein said copper is present in said alloy in an amount between 30 and 35 atomic per cent.
6. A method as claimed in claim 3 wherein said non-ferromagnetic material is platinum.
7. A method as claimed in claim 3 wherein said non-ferromagnetic material is tin.

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