[0005] Advanced TMR devices with even higher TMR will require a reduction in the resistance-area product (RA), which means that the MgO barrier layers will need to be made thinner. However, as the MgO thickness decreases the TMR also decreases, which is believed due, in part, to diffusion of boron into the MgO barrier layer. The reduction in MgO thickness also results in an undesirable increase in interlayer coupling field (H_{int}), i.e., the strength of the magnetic coupling field between the reference layer and the free layer. A large H_{int} degrades the performance of the TMR read head. It is important to have low values of H_{int} as the MgO barrier layer thickness is reduced.

[0006] What is needed is a TMR device with a thin MgO barrier layer and thus reduced RA, but with high TMR and low H_{int}.

SUMMARY OF THE INVENTION

[0007] Embodiments of this invention relate to a TMR device with a thin MgO barrier layer and a nitrogen-containing layer between the MgO barrier layer and the free and/or reference boron-containing ferromagnetic layers. In one embodiment the free ferromagnetic layer includes a boron-containing layer and a trilayer nanolayer structure between the MgO barrier layer and the boron-containing layer. The trilayer nanolayer structure includes a thin Co, Fe or CoFe first nanolayer in contact with the MgO layer, a thin FeN or CoFeN second nanolayer on the first nanolayer and a thin Co, Fe or CoFe third nanolayer on the FeN or CoFeN nanolayer between the FeN or CoFeN nanolayer and the boron-containing layer. If the reference ferromagnetic layer also includes a boron-containing layer then a similar trilayer nanolayer structure may be located between the boron-containing layer and the MgO barrier layer. TMR devices according to embodiments of the invention exhibit greater values of TMR and lower values of interlayer coupling field (H_{int}) for thin MgO barrier layers than TMR devices without the nitrogen-containing layers.

[0007a] According to a first aspect, there is provided a tunneling magnetoresistive (TMR) device comprising: a substrate; a first ferromagnetic layer on the substrate; a tunneling barrier layer consisting essentially of MgO on the first ferromagnetic layer; and a second

ferromagnetic layer on the tunneling barrier layer; wherein one of said first and second ferromagnetic layers is a free ferromagnetic multilayer having an in-plane magnetization direction substantially free to rotate in the presence of an external magnetic field, the free ferromagnetic multilayer comprising a boron-containing layer and a nitrogen-containing layer between the barrier layer and the boron-containing layer; and wherein the other of said first and second ferromagnetic layers is a reference ferromagnetic layer having an in-plane magnetization direction substantially prevented from rotation in the presence of an external magnetic field.

[0007b] According to a second aspect, there is provided a tunneling magnetoresistive (TMR) read head comprising: a first shield layer of magnetically permeable material; a reference ferromagnetic layer on the first shield layer and having an in-plane magnetization direction substantially prevented from rotation in the presence of an external magnetic field; an electrically insulating tunneling barrier layer consisting essentially of MgO on and in contact with the reference layer; a free ferromagnetic layer on the tunneling barrier layer and having an in-plane magnetization direction oriented substantially orthogonal to the magnetization direction of the reference layer in the absence of an external magnetic field, the free ferromagnetic layer comprising a first nanolayer in contact with the barrier layer and selected from Co, Fe and an alloy consisting of Co and Fe, a second nanolayer in contact with the first nanolayer and selected from a FeN alloy and a CoFeN alloy, and a boron-containing ferromagnetic layer on the second nanolayer; a capping layer on the free ferromagnetic layer; and a second shield layer of magnetically permeable material on the capping layer.

[0008] For a fuller understanding of the nature and advantages of the present invention, reference should be made to the following detailed description taken together with the accompanying figures.

What is claimed is:

1. A tunneling magnetoresistive (TMR) device comprising:

a substrate;

a first ferromagnetic layer on the substrate;

a tunneling barrier layer consisting essentially of MgO on the first ferromagnetic layer; and

a second ferromagnetic layer on the tunneling barrier layer;

wherein one of said first and second ferromagnetic layers is a free ferromagnetic multilayer having an in-plane magnetization direction substantially free to rotate in the presence of an external magnetic field, the free ferromagnetic multilayer comprising a boron-containing layer and a nitrogen-containing layer between the barrier layer and the boron-containing layer; and

wherein the other of said first and second ferromagnetic layers is a reference ferromagnetic layer having an in-plane magnetization direction substantially prevented from rotation in the presence of an external magnetic field.

2. The device of claim 1 wherein said free ferromagnetic multilayer further comprises a first nanolayer in contact with the barrier layer and selected from Co, Fe and an alloy consisting of Co and Fe, and wherein said nitrogen-containing layer is a second nanolayer in contact with the first nanolayer and selected from a FeN alloy and a CoFeN alloy.

3. The device of claim 2 wherein the first and second nanolayers have a combined thickness greater than or equal to 2 Å and less than or equal to 8 Å.

4. The device of claim 2 wherein said FeN alloy has a composition of the form $Fe_{(100-x)}N_x$, where x is between 1 and 50 atomic percent, and wherein said CoFeN alloy has a composition of the form $(Co_xFe_{(100-x)})_{(100-y)}N_y$, where x is between 20 and 80 atomic percent and y is between 1 and 50 atomic percent.

5. The device of claim 2 wherein said free ferromagnetic multilayer further comprises a third nanolayer in contact with the second nanolayer and selected from Co, Fe and an alloy consisting of Co and Fe.

6. The device of claim 1 wherein said boron-containing layer is an alloy comprising Co, Fe and B.

7. The device of claim 6 wherein said boron-containing layer is an alloy further comprising Ta.

8. The device of claim 1 wherein said free ferromagnetic multilayer is the first ferromagnetic layer, and said reference ferromagnetic layer is the second ferromagnetic layer.

9. The device of claim 1 wherein said reference ferromagnetic layer is the first ferromagnetic layer, and said free ferromagnetic multilayer is the second ferromagnetic layer.

10. The device of claim 1 wherein said reference ferromagnetic layer is part of an antiparallel (AP) pinned structure comprising a first AP-pinned (AP1) ferromagnetic layer having an in-plane magnetization direction, a second AP-pinned (AP2) ferromagnetic layer adjacent the tunneling barrier layer and having an in-plane magnetization direction substantially antiparallel to the magnetization direction of the AP1 layer, and an AP coupling (APC) layer between and in contact with the AP1 and AP2 layers, wherein the reference layer is the AP2 layer.

11. The device of claim 1 wherein said reference ferromagnetic layer is a reference ferromagnetic multilayer comprising a boron-containing layer and a nitrogen-containing layer between the barrier layer and the boron-containing layer.

12. A tunneling magnetoresistive (TMR) read head comprising:

a first shield layer of magnetically permeable material;

a reference ferromagnetic layer on the first shield layer and having an in-plane magnetization direction substantially prevented from rotation in the presence of an external magnetic field;

an electrically insulating tunneling barrier layer consisting essentially of MgO on and in contact with the reference layer;

a free ferromagnetic layer on the tunneling barrier layer and having an in-plane magnetization direction oriented substantially orthogonal to the magnetization direction of the reference layer in the absence of an external magnetic field, the free ferromagnetic layer comprising a first nanolayer in contact with the barrier layer and selected from Co, Fe and an alloy consisting of Co and Fe, a second nanolayer in contact with the first nanolayer and selected from a FeN alloy and a CoFeN alloy, and a boron-containing ferromagnetic layer on the second nanolayer;

a capping layer on the free ferromagnetic layer; and

a second shield layer of magnetically permeable material on the capping layer.

13. The read head of claim 12 wherein said FeN alloy has a composition of the form $Fe_{(100-x)}N_x$, where x is between 1 and 50 atomic percent, and said CoFeN alloy has a composition of the form $(Co_xFe_{(100-x)})_{(100-y)}N_y$, where x is between 20 and 80 atomic percent and y is between 1 and 50 atomic percent.

14. The read head of claim 12 further comprising a third nanolayer in contact with the second nanolayer and selected from Co, Fe and an alloy consisting of Co and Fe, and wherein said boron-containing layer is in contact with the third nanolayer.

15. The read head of claim 14 wherein the combined thicknesses of the first, second and third nanolayers is greater than or equal to 3 Å and less than or equal to 12 Å.

16. The read head of claim 12 wherein said reference layer comprises a boron-containing ferromagnetic layer, a first nanolayer in contact with the barrier layer and selected from Co, Fe and an alloy consisting of Co and Fe, and a second nanolayer between the boron-containing layer and the first nanolayer and selected from a FeN alloy and a CoFeN alloy.

17. The read head of claim 12 further comprising an antiparallel (AP) pinned structure between the first shield layer and the barrier layer and comprising a first AP-pinned (AP1) ferromagnetic layer on the first shield layer and having an in-plane magnetization direction, a second AP-pinned (AP2) ferromagnetic layer having an in-plane magnetization direction substantially antiparallel to the magnetization direction of the AP1, and an AP coupling (APC) layer between and in contact with the AP1 and AP2 layers, and wherein said reference layer is said AP2 layer.