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(54) MAGNETIC MEMORY USING SINGLE DOMAIN SWITCHING BY DIRECT CURRENT

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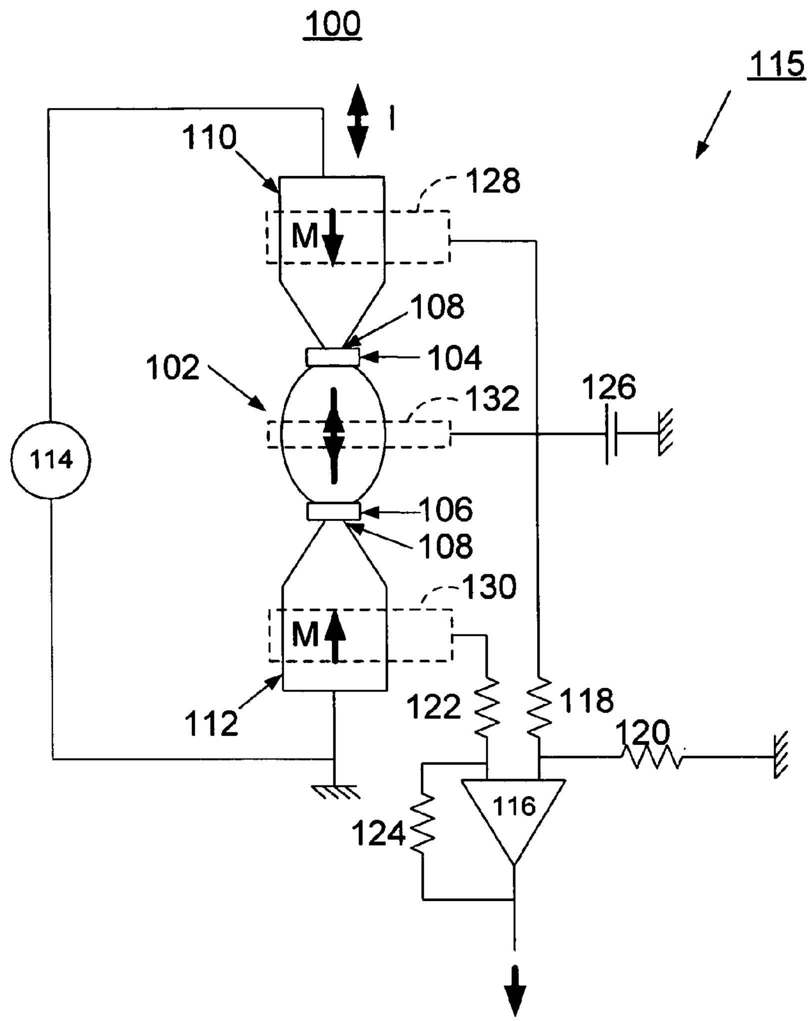
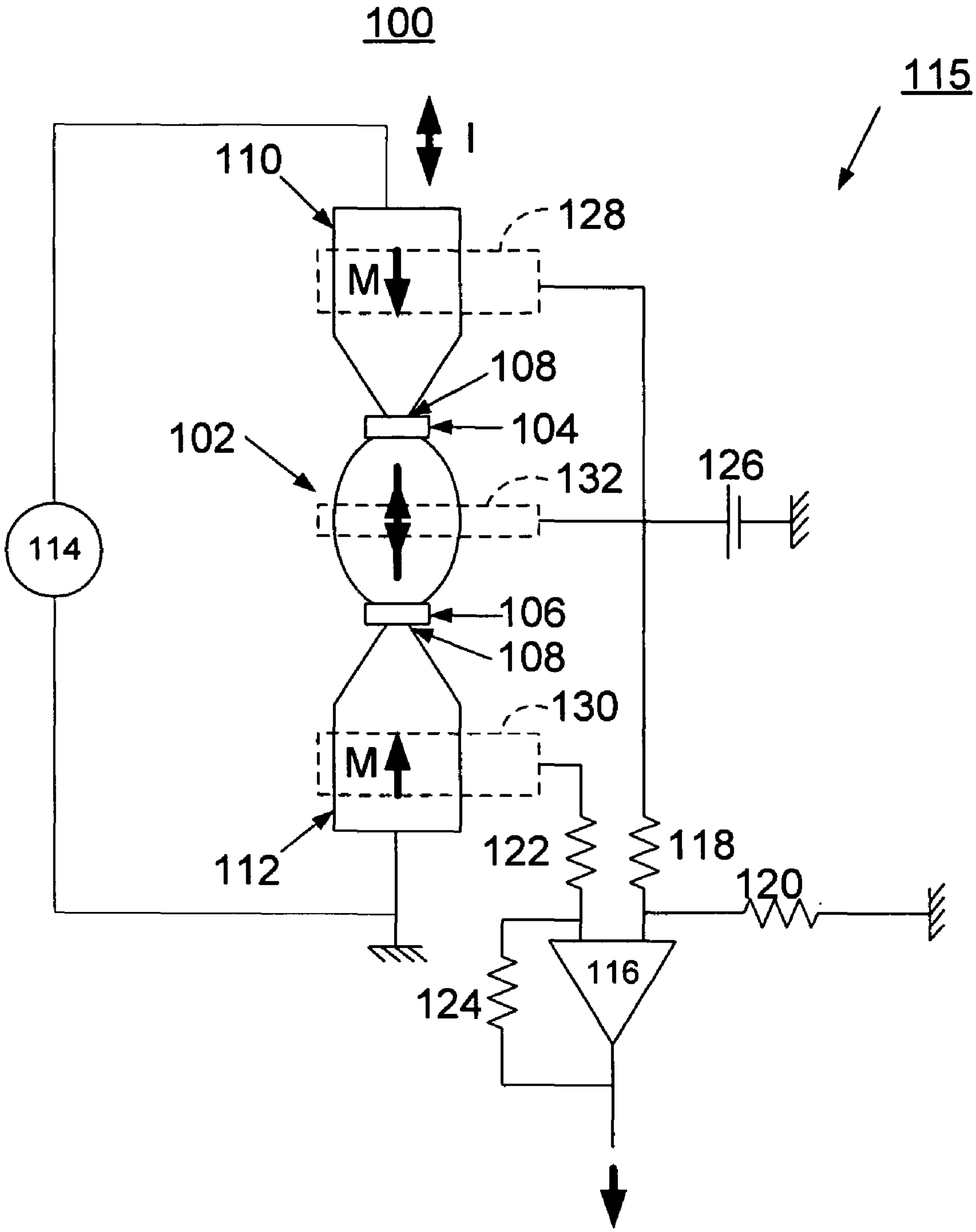
(57) **ABSTRACT**

A method for implementing miniaturization of magnetic random access memory (MRAM) and a magnetic memory using single domain switching by direct current are provided. The magnetic memory preferably includes a half-circle or U-shaped architecture with an exchange biasing pad, such as a FeMn exchange biasing pad that effectively generates a head-to-head magnetization configuration. The magnetic memory also includes nanometer scale notches in order to minimize magnetostatic interaction between a single domain memory element and the spin current sources and to effectively trap the magnetic domain wall. Reading the bit can be carried out by anisotropic magnetoresistance, or by other means of determining the magnetization orientation through resistance measurements, such as a spin valve or a magnetic tunneling junction.




100
115
I
110
128
M
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124

FIG. 1

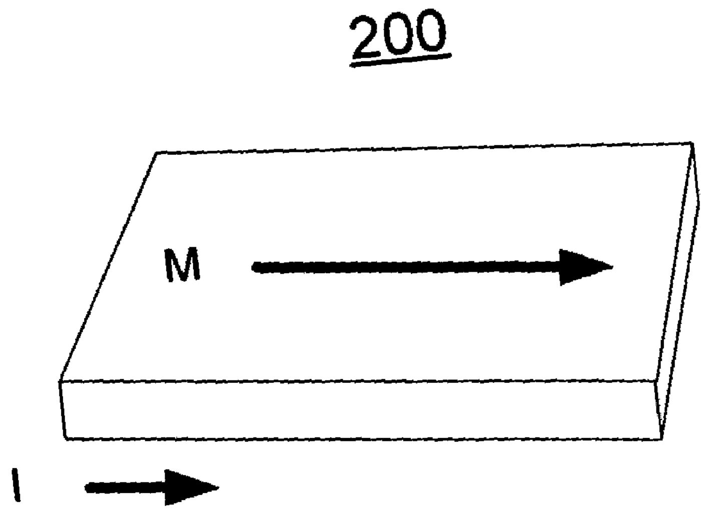

FIG. 2

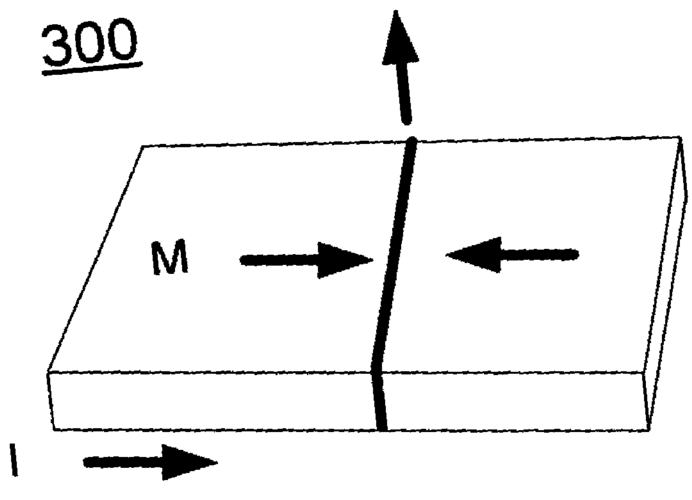

FIG. 3

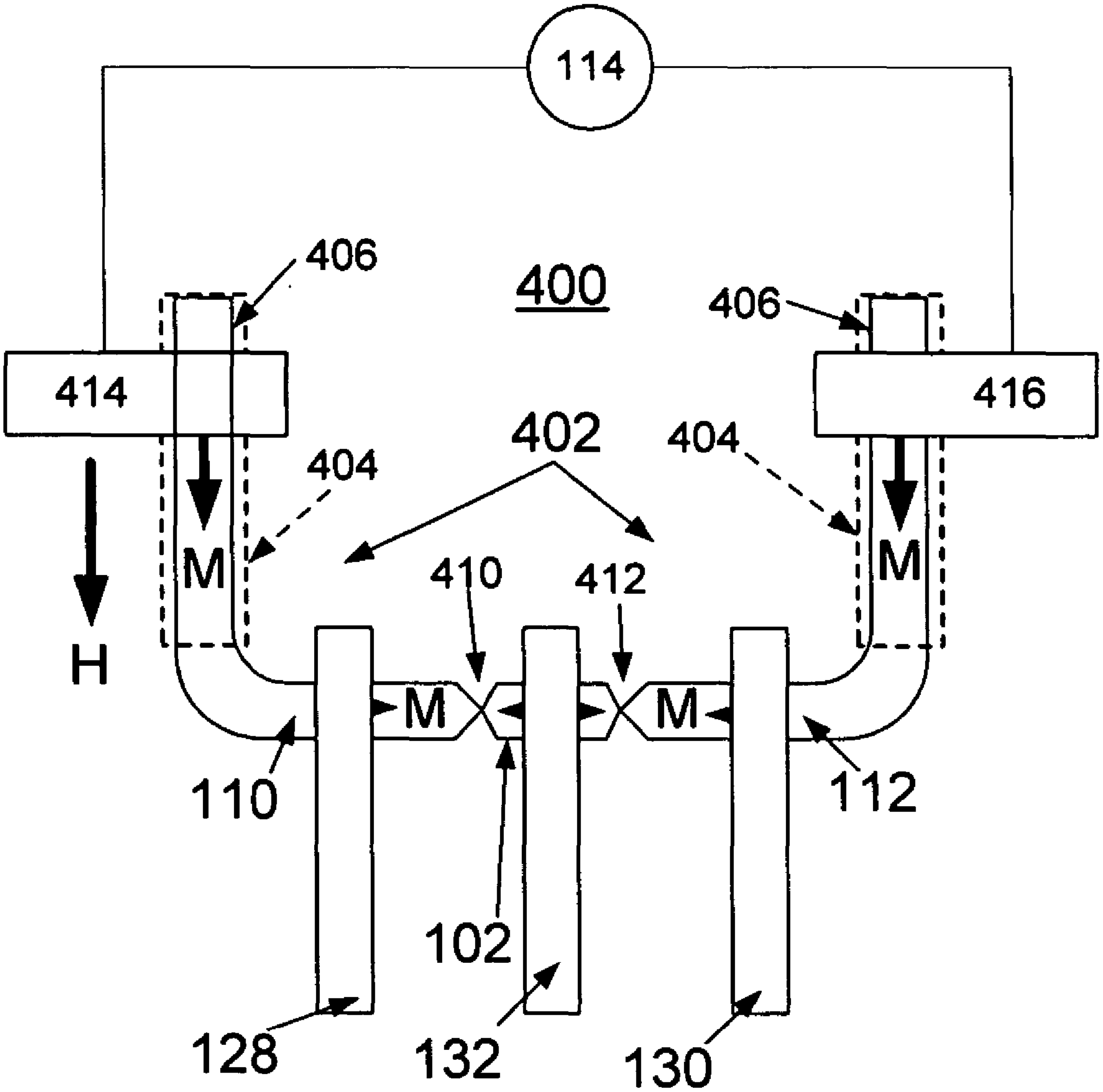
114
406
400
406
414
416
402
404
404
M
M
H
410
412
M
M
110
112
102
128
132
130

FIG. 4

MAGNETIC MEMORY USING SINGLE DOMAIN SWITCHING BY DIRECT CURRENT

CONTRACTUAL ORIGIN OF THE INVENTION

[0001] The United States Government has rights in this invention pursuant to Contract No. W-31-109-ENG-38 between the United States Government and Argonne National Laboratory.

FIELD OF THE INVENTION

[0002] The present invention relates to a method for implementing miniaturization of magnetic random access memory (MRAM) and a magnetic memory using single domain switching by direct current.

DESCRIPTION OF THE RELATED ART

[0003] The development of magnetic random access memory (MRAM) is currently of great interest to the electronics industry due to its promise of high density, fast speed, lower power consumption and non-volatility. MRAM should combine the high speed of a conventional static RAM, the storage capacity of a dynamic random access memory (DRAM) and the non- volatility of flash memory.

[0004] The realization of most magnetic memory and spin-dependent devices is intricately related to the ability to change the magnetization of one or more of the active elements. A common way of switching the magnetization is by generating an external magnetic write field higher than the coercivity of the ferromagnetic layer, which is used to encode the information. However, a potential drawback for this technique is the need for a high external current to induce magnetization reversal. Further, as the critical dimensions decrease, the field localization for selective switching could become a critical concern.

[0005] Conventional MRAM employs a current-induced magnetic field external to the memory cell in the write mode. This field is reversed to respectively write a zero (0) or a one (1). A field external to the cell inherently limits the achievable cell density as an adjacent stray external field can influence adjacent cells.

[0006] There are significant hurdles to be overcome, such as the reduction of cross-talk between the magnetic memory elements during the write cycle due to the high density packing.

[0007] Alternative techniques are being explored for changing the local magnetization other than direct field generation. One recently proposed voltage controlled rotation (VCR) is very appealing, but the fabrication requirements appear to be quite stringent.

[0008] A publication entitled "Pulsed-Current-Induced Domain Wall Propagation in Permalloy Patterns Observed Using Magnetic Force Microscope" by L. Gan, S. H. Chung, K. H. Aschenbach, M. Dreyer, and R. D. Gomez, IEEE Transactions on Magnetics, Vol, 36, No. 5, pps. 3047-**3**049, September **2000**, discloses exploiting the well-known phenomena of domain drag induced by current pulses and applying the technique to micronscale patterned Permalloy structures. The devices that could potentially benefit from these investigations are magnetic tunnel junctions, as well as MRAMs and spin transistors that utilize Permalloy as a spin sensing electrode. The paper describes domain wall motion in patterned 100-160 nm thick Permalloy films and demonstrates the technical feasibility of moving domains with directional specificity. The subject matter of the above-identified publication is incorporated herein by reference.

[0009] A principal object of the present invention is to provide a method for implementing miniaturization of magnetic random access memory (MRAM) and a magnetic memory using single domain switching by direct current pulse.

SUMMARY OF THE INVENTION

[0010] In brief, the present invention provides a method for implementing miniaturization of magnetic random access memory (MRAM) and a magnetic memory using single domain switching by direct current pulse. The magnetic memory includes a structure formed of a ferromagnetic, metallic material defining a single domain island. The single domain island includes a first domain wall position and a second opposing domain wall position. The first domain wall position and second opposing domain wall position are formed by constrictions formed in respective opposed portions of the magnetic memory device.

[0011] In accordance with features of the invention, a magnetic memory is provided that substantially eliminates cross-talk by switching a single domain island through current induced domain wall motion for writing information with current polarity. This is achieved with a current source and current leads with well-defined magnetization, which generate a well-defined spin polarized current at the location of the single domain island.

[0012] The magnetic memory of the invention uses a half-circle or U-shaped architecture with an exchange biasing pad, incorporating any suitable antiferromagnetic material such as a FeMn exchange biasing pad, that effectively generates a stable head-to-head magnetization configuration. The magnetic memory also includes nanometer scale notches in order to minimize magnetostatic interaction between a single domain memory element and the spin current sources and to effectively trap the magnetic domain wall. Reading the bit can be carried out by anisotropic magnetoresistance, or by other means of determining the magnetization orientation through resistance measurements, such as a spin valve or a magnetic tunneling junction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The present invention together with the above and other objects and advantages may best be understood from the following detailed description of the preferred embodiments of the invention illustrated in the drawings, wherein:

[0014] **FIG. 1** is a schematic and block diagram representation of a magnetic memory device of the invention;

[0015] **FIGS. 2 and 3** are diagrams illustrating anisotropic magnetoresistance reading of the magnetic memory device of **FIG. 1** in accordance with the invention; and

[0016] **FIG. 4** is a schematic and block diagram representation illustrating a preferred configuration of the magnetic memory device of **FIG. 1** in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] In accordance with features of the invention, a magnetic memory device is provided that substantially eliminates cross-talk by switching a single domain element or island through current induced domain wall motion and by writing information with current polarity as illustrated and described with respect to **FIG. 1**. This is achieved with a current source and current leads with well-defined magnetization, which generate a well defined spin polarized current at the location of the single domain island. The magnetic memory device of the preferred embodiment uses a half-circle architecture with an exchange biasing pad using any suitable antiferromagnetic material such as FeMn, as illustrated and described with respect to **FIG. 4**, that can generate a stable head-to-head magnetization configuration. This stable head-to-head magnetization configuration assures that only one magnetic domain wall is present in the given magnetic memory cell. The magnetic memory cell of the invention also includes nanometer scale notches, for example, as illustrated and described with respect to **FIG. 4**, in order to minimize magnetostatic interaction between a single domain memory element and the spin current sources and to effectively trap the magnetic domain wall. Reading a stored bit preferably is carried out by anisotropic magnetoresistance (AMR), as illustrated and described with respect to **FIGS. 2 and 3**.

[**0018**] Having reference now to the drawings, in **FIG. 1** there is shown a magnetic memory device of the invention generally designated by reference character **100**. . The magnetic memory device **100** includes a single domain island **102** with an elliptical shape connected to the two spin-injection pads via a pair of nanometer scale constrictions **108**. These nanometer scale constrictions **108** effectively trap the magnetic domain wall either at position **104** or position **106**. These two possible domain wall positions **104** and **106** represent bit "0" and "1" respectively. The pair of constrictions **108** is formed in respective opposed portions **110**, **112** of the elongate magnetic memory device **100** with the single domain island **102** extending between the opposing constrictions **108**.

[**0019**] Directions of magnetizations labeled M of the respective opposed portions **110**, **112** of the elongate magnetic memory device **100** are made antiparallel through the half-circle or U-shaped geometry. Therefore a single magnetic domain wall is formed either at position **104** or **106** depending on the orientation of magnetization of the single domain island **102**, up or down respectively. A direct current source **114** is connected to the magnetic memory device **100** between the respective opposed portions **110**, **112** with a ground potential connection at the portion **112**. The opposing magnetizations in portions **110** and **112** will then generate oppositely spin-polarized current at the location of the single domain island **102** depending on the current polarity of the current source **114**. Therefore portions **110** and **112** are effectively spin-injection pads. The magnetic memory device **100** can be formed of any ferromagnetic and metallic material, such as a Permalloy.

[**0020**] Writing a zero or a one is provided by selectively reversing a current polarity of the current source **114** for switching the single domain island **102** through current induced domain wall motion. For example, the relative orientation of magnetic states of a zero or a one of the single domain island **102** are changed corresponding to the current polarity, selectively moving the domain wall between the first domain wall position **104** and the second opposing domain wall position **106**. Respective opposing constrictions **108** adjacent to the first domain wall position **104** and the second opposing domain wall position **106** functions to keep the domain wall in place or effectively trap the magnetic domain wall.

[**0021**] In accordance with features of the invention, the magnetic memory device **100** reduces the critical current for domain wall motion as compared to conventional MRAM designs using an external magnetic field for magnetization control. The magnetic memory device **100** enables easier fabrication eliminating the need for the required multiple layers of such conventional MRAM designs. The magnetic memory device **100** enables easier miniaturization, avoiding the cross-talk problem and hard localization of conventional MRAM designs using an external magnetic field for magnetization control.

[**0022**] Reading the magnetic memory device **100** is implemented with an exemplary anisotropic magnetoresistance (AMR) read circuit generally designated by reference character **115**. Read circuit **115** includes an operational amplifier **116** together with a plurality of biasing resistors **118**, **120**, **122**, **124** and a voltage source **126**. The biasing resistors **118**, **122** are respectively connected between an input of a differential operational amplifier **116** and a first electrode **128** and a second electrode **130**. The first electrode **128** and the second electrode **130** are connected to the respective opposed portions **110**, **112** of the elongate magnetic memory device **100**. A third electrode **132** is connected between the single domain island **102** and the voltage source **126**. A resistance difference between the first electrode **128** and the second electrode **130** is detected by read circuit **115** with an output of the operational amplifier **116** indicating a zero or a one stored by the magnetic memory device **100**.

[**0023**] Referring also to **FIGS. 2 and 3**, reading the stored bit or magnetic state of the single domain island **102** preferably is carried out by anisotropic magnetoresistance (AMR).

[**0024**] In **FIG. 2**, there is shown a higher resistance portion of the magnetic memory device **100** generally designated by reference character **200**. Higher resistance results where the magnetic moment M is parallel or antiparallel to current flow **1**. This is the case when there is no domain wall present at either position **104** or **106**.

[**0025**] In **FIG. 3**, there is shown a lower resistance portion of the magnetic memory device **100** generally designated by reference character **300**. Lower resistance results where the magnetic moment M is perpendicular to current flow **1**. A domain wall between head-to-head magnetic domains will have a magnetic moment in the plane of the domain wall. Therefore the low resistance will occur when there is a domain wall present at either position **104** or **106**.

[**0026**] Reading the magnetic memory device **100** by anisotropic magnetoresistance (AMR) tests for the presence of the magnetic domain wall at the first domain wall position **104** or the second opposing domain wall position **106** in **FIG. 1**. When magnetic domain wall is trapped at either one of the notches **108**, magnetization is perpendicular to the direction of the current flow. This provides the low resistance state. When no magnetic domain wall exists at the notch, magnetization is parallel of antiparallel to the direction of the current flow. This provides the high resistance state.

[0027] Referring also to **FIG. 4** there is shown a preferred configuration of the magnetic memory device **100** generally designated by reference character **400** in accordance with the invention. The magnetic memory device configuration **400** includes a half-circle or U-shaped architecture generally designated by reference character **402** with an exchange biasing pad **404**, made out of any suitable antiferromagnetic material such as a FeMn exchange biasing pad, provided together with respective upper, generally parallel arm portions **406** of the U-shaped configuration **402**.

[0028] Exchange biasing pads **404** are provided to effectively generate a stable head-to-head magnetization configuration at the single domain island **102** and between memory device portions **110** and **112**.

[0029] The magnetic device configuration **400** also includes a plurality of nanometer scale notches **410**, **412** in order to minimize magnetostatic interaction between a single domain memory island **102** and the spin-injection pads **110**, **112** and to effectively trap the magnetic domain wall at positions **410** and **412**. The nanometer scale notches **410**, **412** serve to isolate the single domain island **102** magnetically, thus trapping the domain wall at the desired location.

[0030] The current source **114** is connected between a pair of electrodes **414**, **416**. Electrodes **414**, **416** are connected to the respective upper generally parallel arm portions **406** of the U-shaped configuration **402**. The domain wall is moved by a direct current pulse provided by current source **114** through the parallel arm portions **406**, which generate the spin-polarized current. Consequently, depending on the polarity of the current pulse the domain wall positions selectively proximate either of the opposed notches **410**, **412**.

[0031] The presence of the domain wall provides a relative low resistance to current flow, thus the zero or one is established by positioning the domain wall at either one of the predefined notch **410**, **412**. The state of the magnetic memory device **100** is then read as a zero or one using an anisotropic magnetoresistance (AMR) read circuit **115** of **FIG. 1** connected to the illustrated electrodes **128**, **132**, **130**.

[0032] In accordance with features of the invention, the use of direct current pulses through the magnetic memory device **100** to switch the single domain magnetization, rather than to induce a larger magnetic field external to the cell, substantially decreases the overall area affected by stray fields thus addressing a constraint to increased cell density. Additionally, the memory device configuration **400** with the notches **410**, **412** provides a simple configuration for fabrication. It should be understood that reading the bit could be carried out by anisotropic magnetoresistance, or by other means of determining the magnetization orientation through resistance measurements, such as a spin valve or a magnetic tunneling junction.

[0033] While the present invention has been described with reference to the details of the embodiments of the invention shown in the drawing, these details are not intended to limit the scope of the invention as claimed in the appended claims.

What is claimed is:

1. A magnetic memory device comprising:

a structure formed of a ferromagnetic, metallic material defining a single domain island;

said single domain island being connected to a pair of spin-injection pads via a pair of nanoscale constrictions defining a first domain wall position and a second opposing domain wall position; and

a direct current source connected to the magnetic memory device for single domain switching.

2. A magnetic memory device as recited in claim 1 wherein said structure includes a generally U-shaped configuration.

3. A magnetic memory device as recited in claim 2 wherein said U-shaped configuration includes a pair of spaced apart, generally parallel arm portions extending generally perpendicular to said single domain island.

4. A magnetic memory device as recited in claim 3 includes an exchange biasing pad provided together with respective generally parallel arm portions.

5. A magnetic memory device as recited in claim 4 wherein said exchange biasing pad include a layer formed of a selected antiferromagnetic material selected from a group including FeMn.

6. A magnetic memory device as recited in claim 1 wherein said constrictions include nanometer scale notches for isolating said single domain island magnetically.

7. A magnetic memory device as recited in claim 1 wherein said direct current source switches said single domain island through current induced domain wall motion for writing information with current polarity.

8. A magnetic memory device as recited in claim 1 wherein said direct current source provides a spin polarized current through said spin-injection pads.

9. A magnetic memory device as recited in claim 2 wherein said direct current source is connected between said pair of spaced apart, generally parallel arm portions.

10. A magnetic memory device as recited in claim 1 includes an anisotropic magnetoresistance (AMR) read circuit for reading a state of said single domain island.

11. A magnetic memory device as recited in claim 10 wherein said anisotropic magnetoresistance (AMR) read circuit includes an operational amplifier and a plurality of biasing resistors connected to said operational amplifier and a pair of electrodes connected to said opposed portions of the elongate magnetic memory device.

12. A magnetic memory device as recited in claim 11 wherein said anisotropic magnetoresistance (AMR) read circuit further includes a voltage source connected to said single domain island.

13. A magnetic memory as recited in claim 11 wherein said operational amplifier of said anisotropic magnetoresistance (AMR) read circuit provides an output indicating a zero or a one stored by the magnetic memory device.

14. A magnetic memory as recited in claim 13 wherein said zero or said one stored by the magnetic memory device is selectively written by said direct current single domain switching through current induced domain wall motion with current polarity.

15. A method for implementing a magnetic random access memory (MRAM) comprising the steps of:

providing a magnetic memory structure formed of a thin film patterned structure of ferromagnetic, metallic material defining a single domain island; said single domain island being connected to a pair of spin-injection pads via nanoscale notches defining a first domain wall position and a second opposing domain wall position;

providing a direct current source coupled to said magnetic memory structure for writing information with current polarity for selectively switching a magnetic state of said single domain island through current induced domain wall motion between a first domain wall position and a second opposing domain wall position;

providing a read circuit coupled to said magnetic memory structure for reading said magnetic state of said single domain island.

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