What is claimed is:

1. A spin torque transfer memory cell structure, comprising:

a tunneling barrier material positioned between a ferromagnetic storage material and a pinned ferromagnetic material in contact with an antiferromagnetic material; and

a multiferroic material in contact with the ferromagnetic storage material;

wherein the antiferromagnetic material, the ferromagnetic storage material, and the pinned ferromagnetic material are located between a first electrode and a second electrode.

2. The memory cell structure of claim 1, including a third electrode configured to provide an electric field to the multiferroic material responsive to an applied voltage between the third electrode and at least one of the first electrode and the second electrode.

3. The memory cell structure of claim 2, wherein the electric field provided to the multiferroic material is sufficient to:

induce a change in antiferromagnetic and/or ferromagnetic ordering of the multiferroic material; and

provide antiferromagnetic exchange coupling and/or ferromagnetic coupling between the multiferroic material and the ferromagnetic storage material such that a magnetization of the ferromagnetic storage material is altered.

4. The memory cell structure of claim 2, wherein the third electrode is a gate of a vertical access device.

5. The memory cell structure of any one of claims 1 to 4, including a third electrode and a fourth electrode configured to provide an electric field to the multiferroic material responsive to a voltage applied between the third electrode and the fourth electrode.

6. The memory cell structure of claim 5, wherein at least one of the third electrode and the fourth electrode is gate of a vertical access device coupled to the spin torque transfer memory cell structure.

7. The memory cell structure of claim 6, wherein the at least one of the third and the fourth electrode is in contact with the multiferroic material.

8. The memory cell structure of any one of claims 1 to 4, wherein the antiferromagnetic material is a synthetic antiferromagnet.

9. The memory cell structure of claim 1, wherein the multiferrioc material is bismuth ferrite ($BiFeO_3$).

10. The memory cell structure of any one of claims 1 to 4, wherein the first electrode and the second electrode are configured to provide an electric field to the multiferroic material responsive to a voltage applied between the first electrode and the second electrode.

11. A spin torque transfer memory cell, comprising:

a magnetic tunneling junction (MTJ) element positioned between a first electrode and a second electrode;

a multiferroic material in contact with a ferromagnetic storage material of the MTJ element; and

an access device coupled to the MTJ element.

12. The memory cell of claim 11, wherein the access device includes a first gate electrode and a second gate electrode.

13. The memory cell of claim 12, wherein at least one of the first gate electrode and the second gate electrode is configured to provide an electric field to the multiferroic material responsive to a voltage applied between the first electrode and at least one of the first gate electrode and the second gate electrode.

14. The memory cell of claim 12, wherein the multiferroic material includes a first portion coupled between the first gate electrode and the ferromagnetic storage material.

15. The memory cell of claim 14, wherein the multiferroic material includes a second portion coupled between the second gate electrode and the ferromagnetic storage material.

16. The memory cell of claim 14, wherein the first portion of the multiferroic material is configured to be a gate oxide material associated with the access device.

17. The memory cell of any one of claims 11 to 16, wherein the first portion of the multiferroic material is located above a gate oxide material associated with the access device.

18. The memory cell of any one of claims 11 to 16, wherein the multiferroic material includes:

a first portion coupled to a first edge portion of the ferromagnetic storage material; and

a second portion coupled to a second edge portion of the ferromagnetic storage material.

19. The memory cell of any one of claims 11 to 16, wherein the tunneling barrier material is magnesium oxide (MgO).

20. A method of operating a spin torque transfer (STT) memory cell, the method comprising:

altering a magnetization of a free ferromagnetic storage material of a magnetic tunneling junction (MTJ) element of the STT memory cell by providing an electric field to a multiferroic material in contact with the ferromagnetic storage material;

wherein the MTJ element includes:

a pinned ferromagnetic material;

an antiferromagnetic material; and

a tunneling barrier material positioned between the ferromagnetic storage material and the pinned ferromagnetic material.

21. The method of claim 20, wherein altering the magnetization of the free ferromagnetic material includes switching a magnetization direction from a first configuration to a second configuration.

22. The method of claim 20, including switching the magnetization direction from at least one of:

a configuration parallel to a magnetization direction of the pinned ferromagnetic material to a magnetization direction antiparallel to the magnetization direction of the pinned ferromagnetic material; and

a configuration antiparallel to the magnetization direction of the pinned ferromagnetic material to a magnetization direction parallel to the magnetization direction of the pinned ferromagnetic material.

23. The method of claim 20, including determining a state of the STT memory cell induced by the electric field provided to the multiferroic material.

24. The method of claim 20, including subsequently providing a programming current through the MTJ element.

25. The method of claim 20, wherein providing the electric field to the multiferroic material includes applying a voltage difference between a top electrode and a bottom electrode of the STT memory cell.

26. The method of claim 20, wherein the STT memory cell includes a bottom electrode, a top electrode, and at least one additional electrode, and wherein providing the electric field to the multiferroic material includes applying a voltage difference between at least one of the top electrode and bottom electrode and at least one of the at least one additional electrode.

27. The method of any one of claims 20 to 26, wherein the STT memory cell includes a bottom electrode, a top electrode, a first additional electrode, and a second additional electrode, and wherein providing the electric field to the multiferroic material includes applying a voltage difference between the first and the second additional electrode.

28. The method of claim 27, wherein the first and second additional electrodes are gate electrodes of a vertical access device associated with the STT memory cell.

29. The method of claim 27, wherein providing the electric field to the multiferroic material includes providing an electric field having a magnitude sufficient to:

induce a change in antiferromagnetic ordering of the multiferroic material; and

provide antiferromagnetic exchange coupling between the multiferroic material and the ferromagnetic storage material.

30. The method of any one of claims 20 to 26, wherein a first portion of the multiferroic material is configured to be a gate oxide material associated with an access device associated with the STT memory cell.

What is claimed is:

1. A spin torque transfer memory cell structure, comprising:

a tunneling barrier material positioned between a ferromagnetic storage material and a pinned ferromagnetic material in contact with an antiferromagnetic material; and

a multiferroic material in contact with the ferromagnetic storage material;

wherein the antiferromagnetic material, the ferromagnetic storage material, and the pinned ferromagnetic material are located between a first electrode and a second electrode; and

a third electrode configured to provide an electric field to the multiferroic material responsive to an applied voltage between the third electrode and at least one of the first electrode and the second electrode;

wherein the third electrode is a gate of a vertical access device.

2. The memory cell structure of claim 1, wherein the electric field provided to the multiferroic material is sufficient to:

induce a change in antiferromagnetic and/or ferromagnetic ordering of the multiferroic material; and

provide antiferromagnetic exchange coupling and/or ferromagnetic coupling between the multiferroic material and the ferromagnetic storage material such that a magnetization of the ferromagnetic storage material is altered.

3. The memory cell structure of claim 1, including a fourth electrode configured to provide an electric field to the multiferroic material responsive to a voltage applied between the third electrode and the fourth electrode.

4. The memory cell structure of claim 3, wherein the fourth electrode is a gate of the vertical access.

5. The memory cell structure of claim 25, wherein the at least one of the third and the fourth electrode is in contact with the multiferroic material.

6. The memory cell structure of claim 1, wherein the antiferromagnetic

material is a synthetic antiferromagnet.

7. The memory cell structure of claim 1, wherein the multiferrioc material is bismuth ferrite ($BiFeO_3$).

8. The memory cell structure of claim 1, wherein the first electrode and the second electrode are configured to provide an electric field to the multiferroic material responsive to a voltage applied between the first electrode and the second electrode.

9. A spin torque transfer memory cell, comprising:

a magnetic tunneling junction (MTJ) element positioned between a first electrode and a second electrode;

a multiferroic material in contact with a ferromagnetic storage material of the MTJ element; and

an access device coupled to the MTJ element;

wherein the access device includes a first gate electrode and a second gate electrode; and

wherein at least one of the first gate electrode and the second gate electrode is configured to provide an electric field to the multiferroic material responsive to a voltage applied between the first electrode and at least one of the first gate electrode and the second gate electrode.

10. The memory cell of claim 9, wherein the multiferroic material includes a first portion coupled between the first gate electrode and the ferromagnetic storage material.

11. The memory cell of claim 10, wherein the multiferroic material includes a second portion coupled between the second gate electrode and the ferromagnetic storage material.

12. The memory cell of claim 10, wherein the first portion of the multiferroic material is configured to be a gate oxide material associated with the access device.

13. The memory cell of claim 10, wherein the first portion of the multiferroic material is located above a gate oxide material associated with the access device.

14. The memory cell of claim 9, wherein the multiferroic material includes:

a first portion coupled to a first edge portion of the ferromagnetic storage material; and

a second portion coupled to a second edge portion of the ferromagnetic storage material.

15. The memory cell of claim 9, wherein the tunneling barrier material is magnesium oxide (MgO).

16. A method of operating a spin torque transfer (STT) memory cell, the method comprising:

altering a magnetization of a free ferromagnetic storage material of a magnetic tunneling junction (MTJ) element of the STT memory cell by providing an electric field to a multiferroic material in contact with the ferromagnetic storage material;

wherein the MTJ element includes:

a pinned ferromagnetic material;

an antiferromagnetic material; and

a tunneling barrier material positioned between the ferromagnetic storage material and the pinned ferromagnetic material;

wherein the STT memory cell includes a bottom electrode, a top electrode, a first additional electrode, and a second additional electrode; and wherein providing the electric field to the multiferroic material includes applying a voltage difference between the first and the second additional electrodes, wherein the first and second additional electrodes are gate electrodes of a vertical, access device associated with the STT memory cell.

17. The method of claim 16, wherein altering the magnetization of the free ferromagnetic material includes switching a magnetization direction from a first configuration to a second configuration.

18. The method of claim 16, including switching the magnetization direction from at least one of:

a configuration parallel to a magnetization direction of the pinned ferromagnetic material to a magnetization direction antiparallel to the magnetization direction of the pinned ferromagnetic material; and

a configuration antiparallel to the magnetization direction of the pinned ferromagnetic material to a magnetization direction parallel to the magnetization direction of the pinned ferromagnetic material.

19. The method of claim 16, including determining a state of the STT memory cell induced by the electric field provided to the multiferroic material.

20. The method of claim 16, including subsequently providing a programming current through the MTJ element.

21. The method of claim 16, wherein providing the electric field to the multiferroic material includes applying a voltage difference between the top electrode and the bottom electrode of the STT memory cell.

22. The method of claim 16 wherein providing the electric field to the multiferroic material includes applying a voltage difference between at least one of the top electrode and bottom electrode and at least one of the at least one additional electrode.

23. The method of claim 16, wherein providing the electric field to the multiferroic material includes providing an electric field having a magnitude sufficient to:

induce a change in antiferromagnetic ordering of the multiferroic material; and

provide antiferromagnetic exchange coupling between the multiferroic material and the ferromagnetic storage material.

24. The method of claim 16, wherein a first portion of the multiferroic

material is configured to be a gate oxide material associated with an access device associated with the STT memory cell.

25. A spin torque transfer memory cell structure, comprising:

a tunneling barrier material positioned between a ferromagnetic storage material and a pinned ferromagnetic material in contact with an antiferromagnetic material;

a multiferroic material in contact with the ferromagnetic storage material; wherein the antiferromagnetic material, the ferromagnetic storage material, and the pinned ferromagnetic material are located between a first electrode and a second electrode;

a third electrode and a fourth electrode configured to provide an electric field to the multiferroic material responsive to a voltage applied between the third electrode and the fourth electrode; and

wherein at least one of the third electrode and the fourth electrode is gate of a vertical access device coupled to the spin torque transfer memory cell structure.

26. A spin torque transfer memory cell, comprising:

a magnetic tunneling junction (MTJ) element positioned between a first electrode and a second electrode;

a multiferroic material in contact with a ferromagnetic storage material of the MTJ element; and

an access device coupled to the MTJ element;

wherein the access device includes a first gate electrode and a second gate electrode;

wherein the multiferroic material includes a first portion coupled between the first gate electrode and the ferromagnetic storage material; and

wherein the first portion of the multiferroic material is configured to be a gate oxide material associated with the access device.