What is claimed is:

1. A spin torque transfer (STT) 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,

wherein the tunneling barrier material is a multiferroic material, and wherein the antiferromagnetic material, the ferromagnetic storage material, and the pinned ferromagnetic material are positioned 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 and/or ferromagnetic exchange 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.

7. The memory cell structure of claim 5, wherein a dielectric material is positioned between the multiferroic material and the third and the fourth electrode.

8. The memory cell structure of any one of claims 1 to 4, wherein the multiferroic material is in contact with the ferromagnetic storage material and the pinned ferromagnetic
material;

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

10. The memory cell structure of any one of claims 1 to 4, wherein the multiferroic material has a thickness of about 1 nanometer (nm) or less.

11. A spin torque transfer (STT) memory cell, comprising:

a stack structure including:

a first magnetic tunneling junction (MTJ) element positioned between a top electrode and a bottom electrode, wherein a tunneling barrier material of the first MTJ is a first multiferroic material;

a second MTJ element positioned between the top electrode and the bottom electrode, wherein a tunneling barrier material of the second MTJ is a second multiferroic material; and

an access device coupled to the stack structure.

12. The memory cell of claim 11, wherein the access device is a vertical access device and wherein the first and the second multiferroic materials are located between a first gate electrode and a second gate electrode of the vertical access device.

13. The memory cell of claim 12, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the tunneling barrier material of the first and the second MTJ in association with a programming operation performed on the STT memory cell.

14. The memory cell of claim 11, wherein:

the first multiferroic material is positioned between a first ferromagnetic storage material and a first pinned ferromagnetic material associated with the first MTJ element; and

the second multiferroic material is positioned between a second ferromagnetic storage material and a second pinned ferromagnetic material associated with the second MTJ element.

15. The memory cell of claim 14, wherein the stack structure includes an antiferromagnetic material positioned between the first and the second pinned ferromagnetic materials.

16. The memory cell of claim 14, wherein the first ferromagnetic storage material is in contact with the top electrode and the second ferromagnetic storage material is in contact with the bottom electrode.

17. The memory cell of any one of claims 11 to 16, wherein the first multiferroic material and the second multiferroic material have different ferroelectric polarizabilities.

18. A spin torque transfer (STT) memory cell, comprising:

a magnetic tunneling junction (MTJ) element positioned between a top electrode and a bottom electrode, wherein a tunneling barrier material of the MTJ is a multiferroic material; and

a vertical access device coupled to the MTJ element.

19. The memory cell of claim 18, wherein the multiferroic material is located between a first gate electrode and a second gate electrode of the vertical access device.

20. The memory cell of claim 19, 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 in association with a programming operation performed on the

STT memory cell.

21. The memory cell of any one of claims 18 to 20, wherein the multiferroic material includes:

a first edge portion aligned with a first edge portion of a ferromagnetic storage material of the MTJ element; and

a second edge portion aligned with a second edge portion of the ferromagnetic storage material of the MTJ element.

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

altering a magnetization direction of a first free ferromagnetic storage material of a first magnetic tunneling junction (MTJ) element of the STT memory cell by providing an electric field to a first multiferroic tunneling barrier material of the first MTJ element.

23. The method of claim 22, wherein altering the magnetization direction of the first free ferromagnetic storage material includes switching the magnetization direction from a first configuration to a second configuration.

24. The method of claim 23, switching the magnetization direction from the first to the second configuration includes at least one of:

switching the magnetization direction from a configuration parallel to a magnetization direction of a pinned ferromagnetic material of the MTJ element to a magnetization direction antiparallel to the magnetization direction of the pinned ferromagnetic material; and

switching the magnetization direction from 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.

25. The method of claim 22, including determining a state of the STT memory cell induced by the electric field provided to the first multiferroic tunneling barrier material.

26. The method of claim 22, including subsequently providing a programming current through the STT memory cell.

27. The method of claim 22, wherein providing the electric field to the first multiferroic tunneling barrier material includes applying a voltage difference between a first gate electrode and a second gate electrode of a vertical access device corresponding to the STT memory cell.

28. The method of any one of claims 22 to 27, including altering a magnetization direction of a second free ferromagnetic storage material of a second MTJ element of the STT memory cell by providing the electric field to a second multiferroic tunneling barrier material of the second MTJ element.

29. The method of claim 28, 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 first multiferroic tunneling barrier material and the second multiferroic tunneling barrier material includes applying a voltage difference between the first and the second additional electrode.

30. The method of claim 29, wherein the first and second additional electrodes are gate electrodes of a vertical access device associated with the STT memory cell.

31. The method of any one of claims 22 to 27, including determining a data state of the STT memory cell responsive to a read current provided through the STT memory cell.

What is claimed is:

1. A spin torque transfer (STT) 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, wherein the tunneling barrier material is a multiferroic material, and wherein the antiferromagnetic material, the ferromagnetic storage material, and the pinned ferromagnetic material are positioned between a first electrode and a second electrode; and

a third electrode and 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, wherein a dielectric material is positioned between the multiferroic material and at least one of the third and fourth electrodes.

2. The memory cell structure of claim 1, wherein the third electrode is 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 and/or ferromagnetic exchange 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 1, wherein the third electrode is a gate of a vertical access device.

5. The memory cell structure of claim 4, wherein at least one of the third electrode and the fourth electrode is gate of a vertical access device.

6. The memory cell structure of claim 1, wherein the multiferroic material is bismuth ferrite (BiFeO3).

7. The memory cell structure of claim 1, wherein the multiferroic material has a thickness of about 1 nanometer (nm) or less.

8. A spin torque transfer (STT) memory cell, comprising:

a stack structure including:

a first magnetic tunneling junction (MTJ) element positioned between a top electrode and a bottom electrode, wherein a tunneling barrier material of the first MTJ is a first multiferroic material;

a second MTJ element positioned between the top electrode and the bottom electrode, wherein a tunneling barrier material of the second MTJ is a second multiferroic material; and

an access device coupled to the stack structure, wherein the access device is a vertical access transistor, and wherein the first and the second multiferroic materials are located between a first gate electrode and a second gate electrode of the vertical access transistor.

9. The memory cell of claim 8, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the tunneling barrier material of the first and the second MTJ in association with a programming operation performed on the STT memory cell.

10. The memory cell of claim 8, wherein:

the first multiferroic material is positioned between a first ferromagnetic storage material and a first pinned ferromagnetic material associated with the first MTJ element; and

the second multiferroic material is positioned between a second ferromagnetic storage material and a second pinned ferromagnetic material associated with the second MTJ element.

11. The memory cell of claim 10, wherein the stack structure includes an antiferromagnetic material positioned between the first and the second pinned ferromagnetic materials.

12. The memory cell of claim 10, wherein the first ferromagnetic storage material is in contact with the top electrode and the second ferromagnetic storage material is in contact with the bottom electrode.

13. The memory cell of claim 8, wherein the first multiferroic material and the second multiferroic material have different ferroelectric polarizabilities.

14. A spin torque transfer (STT) memory cell, comprising:

a magnetic tunneling junction (MTJ) element positioned between a top electrode and a bottom electrode, wherein a tunneling barrier material of the MTJ is a multiferroic material; and

a vertical access transistor coupled to the MTJ element, wherein the multiferroic material is located between a first gate electrode and a second gate electrode of the vertical access transistor.

15. The memory cell of claim 14, 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 in association with a programming operation performed on the STT memory cell.

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

a first edge portion aligned with a first edge portion of a ferromagnetic storage material of the MTJ element; and

a second edge portion aligned with a second edge portion of the ferromagnetic storage material of the MTJ element.

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

altering a magnetization direction of a first free ferromagnetic storage material of a first magnetic tunneling junction (MTJ) element of the STT memory cell by providing an electric field to a first multiferroic tunneling barrier material of the first MTJ element, wherein providing the electric field to the first multiferroic tunneling barrier material includes applying a voltage difference between a first gate electrode and a second gate electrode of a vertical access transistor corresponding to the STT memory cell.

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

19. The method of claim 18, switching the magnetization direction from the first to the second configuration includes at least one of:

switching the magnetization direction from a configuration parallel to a magnetization direction of a pinned ferromagnetic material of the MTJ element to a magnetization direction antiparallel to the magnetization direction of the pinned ferromagnetic material; and

switching the magnetization direction from 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.

20. The method of claim 17, including determining a state of the STT memory cell induced by the electric field provided to the first multiferroic tunneling barrier material.

21. The method of claim 17, including subsequently providing a programming current through the STT memory cell.

22. The method of claim 17, including altering a magnetization direction of a second free ferromagnetic storage material of a second MTJ element of the STT memory cell by providing the electric field to a second multiferroic tunneling barrier material of the second MTJ element.

23. The method of claim 22, wherein the STT memory cell includes a bottom electrode and a top electrode, a first additional electrode, and a second additional electrode between which the first MTJ element and the second MTJ element are.

24. The method of claim 17, including determining a data state of the STT memory cell responsive to a read current provided through the STT memory cell.