What is claimed is:

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

a STT stack including:

a pinned ferromagnetic material in contact with an antiferromagnetic material;

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

a multiferroic material in contact with the ferromagnetic storage material; and

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

a third electrode and a fourth electrode, wherein at least a first portion of the multiferroic material is located between the third and the fourth electrode.

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

3. The memory cell structure of claim 2, wherein the electric field provided to the at least a first portion of 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 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 at least one of the third electrode and the fourth electrode is a gate of a vertical access device coupled to the STT memory cell structure.

5. The memory cell structure of claim 1, including a fifth electrode and a sixth electrode wherein at least a second portion of the multiferroic material is located between the fifth and the sixth electrode.

6. The memory cell structure of claim 5, wherein the fifth electrode and the sixth electrode are configured to provide an electric field to the at least a second portion of the multiferroic material responsive to an applied voltage between the fifth electrode and the sixth electrode.

7. The memory cell structure of any one of claims 1 to 6, wherein the at least one of the third and the fourth electrode is in contact with the at least a first portion of the multiferroic material.

8. The memory cell structure of any one of claims 1 to 6, wherein at least a portion of the at least a first portion of the multiferroic material is located beneath the ferromagnetic storage material

9. The memory cell structure of claim 8, wherein an inner edge portion of the at least a first portion of the multiferroic material is in contact with an inner edge portion of the second electrode.

10. The memory cell structure of claim 8, wherein an outer edge portion of the at least a first portion of the multiferroic material is in line with an outer edge portion of the ferromagnetic storage material.

11. The memory cell structure of any one of claims 1 to 6, wherein an inner edge portion of the at least a first portion of the multiferroic material is in contact with an outer edge portion of the ferromagnetic storage material.

12. The memory cell structure of any one of claims 1 to 6, wherein at least a portion of the at least a first portion of the multiferroic material is in contact with the second electrode and the tunneling barrier material.

13. The memory cell structure of claim 12, wherein an outer edge portion of the at least a first portion of the multiferroic material is in line with an outer edge portion of the tunneling barrier material.

14. The memory cell structure of any one of claims 1 to 6, wherein the multiferroic material is continuous around the ferromagnetic storage material.

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

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

a first multiferroic material having an inner edge portion in contact with a ferromagnetic storage material of the MTJ element; and

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

16. The memory cell of claim 15, wherein the inner edge portion of the first multiferroic material is in contact with a first edge portion of the ferromagnetic storage material.

17. The memory cell of claim 15, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the first multiferroic material responsive to an applied voltage difference between the first gate electrode and the second gate electrode.

18. The memory cell of any one of claims 15 to 17, including a second multiferroic material having an inner edge portion in contact with the ferromagnetic storage material of the MTJ element.

19. The memory cell of claim 18, wherein the inner edge portion of the second multiferroic material is in contact with a second edge portion of the ferromagnetic storage material.

20. The memory cell of claim 18, wherein the second multiferroic material is located between the first gate electrode and the second gate electrode.

21. The memory cell of claim 18, wherein the vertical access device includes a third and a fourth gate electrode, and wherein the memory cell includes at least a third multiferroic material in contact with the ferromagnetic storage material and located between the third and the fourth gate electrode.

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

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

a first multiferroic material having an upper surface portion in contact with a ferromagnetic storage material of the MTJ element; and

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

23. The memory cell of claim 22, wherein an edge portion of the first multiferroic material is in contact with the second electrode.

24. The memory cell of claim 22, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the first multiferroic material responsive to an applied voltage difference between the first gate electrode and the second gate electrode.

25. The memory cell of any one of claims 22 to 24, including a second multiferroic material having an upper surface portion in contact with the ferromagnetic storage material of the MTJ element.

26. The memory cell of claim 25, wherein an edge portion of the second multiferroic material is in contact with the ferromagnetic storage material.

27. The memory cell of claim 25, wherein the second multiferroic material is located between the first gate electrode and the second gate electrode.

28. The memory cell of claim 25, wherein the vertical access device includes a third and a fourth gate electrode, and wherein the memory cell includes at least a third multiferroic material in contact with the ferromagnetic storage material and located between the third and the fourth gate electrode.

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

a first ferromagnetic storage material in contact with a first multiferroic material;

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

a second ferromagnetic storage material in contact with a second multiferroic material;

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

a vertical access device having a first gate electrode and a second gate electrode, wherein the first multiferroic material and the second multiferroic material are located between the first gate electrode and the second gate electrode.

30. The memory cell of claim 29, including an antiferromagnetic material positioned between and in contact with the first and the second pinned ferromagnetic material, the antiferromagnetic material also positioned between the first and the second ferromagnetic material.

31. The memory cell of claim 29, including a third multiferroic material in contact with the first ferromagnetic storage material.

32. The memory cell of claim 31, including a fourth multiferroic material in contact with the second ferromagnetic storage material.

33. The memory cell of claim 32, wherein the first and the third multiferroic materials have a first ferroelectric polarizability, and wherein the second and the

fourth multiferroic materials have a second ferroelectric polarizability that is different than the first ferroelectric polarizability.

34. The memory cell of claim 32, wherein the first multiferroic material is in contact with a first side surface of the first ferromagnetic storage material and the third multiferroic material is in contact with a second side surface of the first ferromagnetic storage material.

35. The memory cell of claim 34, wherein the second multiferroic material is in contact with a first side surface of the second ferromagnetic storage material and the fourth multiferroic material is in contact with a second side surface of the second ferromagnetic storage material.

36. The memory cell of any one of claims 29 to 35, wherein the first multiferroic material and the third multiferroic material are in contact with a top surface of the first ferromagnetic storage material.

37. The memory cell of claim 36, wherein the second multiferroic material and the fourth multiferroic material are in contact with a bottom surface of the second ferromagnetic storage material.

38. The memory cell of any one of claims 29 to 35, wherein the first and the second multiferroic materials have different ferroelectric polarizabilities.

39. The memory cell of claim 38, wherein the first multiferroic material is continuous and surrounds the first ferromagnetic storage material, and wherein the second multiferroic material is continuous and surrounds the second ferromagnetic storage material.

40. The memory cell of claim 38, including a top electrode in contact with the first ferromagnetic storage material and a bottom electrode in contact with the second ferromagnetic storage material.

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

providing, via an applied voltage difference between a first and a second gate electrode of a vertical access device, an electric field to a first multiferroic material in contact with a first ferromagnetic storage material;

wherein the electric field is sufficient to alter a magnetization direction of the first ferromagnetic storage material via exchange coupling between the first multiferroic material and the first ferromagnetic storage material.

42. The method of claim 41, wherein the electric field is sufficient to induce a switching of the magnetization direction of the first ferromagnetic storage material from a first configuration corresponding to a first data state of the STT memory cell to a second configuration corresponding to a second data state of the STT memory cell.

43. The method of claim 42, wherein the switching of the magnetization direction of the first ferromagnetic storage material includes switching the magnetization direction from at least one of:

a configuration parallel to a magnetization direction of a pinned ferromagnetic material coupled to the first ferromagnetic storage 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.

44. The method of claim 41, including subsequently providing a programming current through the STT memory cell element in a current perpendicular to plane (CPP) configuration.

45. The method of claim 44, including determining a data state of the STT memory cell subsequent to providing the programming current.

46. The method of any one of claims 41 to 45, wherein the STT memory cell includes a stack of materials positioned between a bottom electrode and a top electrode, the stack comprising:

the first ferromagnetic storage material;

the first multiferroic material;

an antiferromagnetic material in contact with the pinned ferromagnetic material; and

a tunneling barrier material between the pinned ferromagnetic material and the antiferromagnetic material; and

wherein the first ferromagnetic storage material is in contact with at least one of the bottom electrode and the top electrode.

47. The method of any one of claims 41 to 45, including providing, via an applied voltage difference between a third and a fourth gate electrode of the vertical access device, an electric field to a second multiferroic material in contact with the first ferromagnetic storage material;

wherein the electric field is sufficient to alter a magnetization direction of the first ferromagnetic storage material via exchange coupling between the first multiferroic material and the first ferromagnetic storage material.

48. The method of any one of claims 41 to 45, wherein the method includes:

providing, via the applied voltage difference between the first and the second gate electrode of the vertical access device, the electric field to a second multiferroic material in contact with a second ferromagnetic storage material; and

wherein the electric field is sufficient to alter a magnetization direction of the second ferromagnetic storage material via exchange coupling between the second multiferroic material and the second ferromagnetic storage material.

49. The method of claim 48, wherein the STT memory cell includes a stack of materials positioned between a bottom electrode and a top electrode, the stack comprising:

the first ferromagnetic storage material and the second ferromagnetic storage material;

the first multiferroic material and the second multiferroic material;

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

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

an antiferromagnetic material in contact with and between the first pinned ferromagnetic material and the second pinned ferromagnetic material; and

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.

50. The method of claim 48, wherein the STT memory cell is configured to store at least two data bits.

51. The method of claim 48, wherein the first multiferroic material and the second multiferroic material have different ferroelectric polarizabilities.

What is claimed is:

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

a STT stack including:

a pinned ferromagnetic material in contact with an antiferromagnetic material;

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

a multiferroic material in contact with the ferromagnetic storage material; and

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

a third electrode and a fourth electrode, wherein at least a first portion of the multiferroic material is located between the third and the fourth electrode; and

a fifth electrode and a sixth electrode, wherein at least a second portion of the multiferroic material is located between the fifth and the sixth electrode.

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

3. The memory cell structure of claim 2, wherein the electric field provided to the at least a first portion of 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 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 at least one of the third

electrode and the fourth electrode is a gate of a vertical access device coupled to the STT memory cell structure.

5. The memory cell structure of claim 1, wherein the fifth electrode and the sixth electrode are configured to provide an electric field to the at least a second portion of the multiferroic material responsive to an applied voltage between the fifth electrode and the sixth electrode.

6. The memory cell structure of claim 1, wherein the at least one of the third and the fourth electrode is in contact with the at least a first portion of the multiferroic material.

7. The memory cell structure of claim 1, wherein at least a portion of the at least a first portion of the multiferroic material is located beneath the ferromagnetic storage material

8. The memory cell structure of claim 7, wherein an inner edge portion of the at least a first portion of the multiferroic material is in contact with an inner edge portion of the second electrode.

9. The memory cell structure of claim 7, wherein an outer edge portion of the at least a first portion of the multiferroic material is in line with an outer edge portion of the ferromagnetic storage material.

10. The memory cell structure of claim 1, wherein an inner edge portion of the at least a first portion of the multiferroic material is in contact with an outer edge portion of the ferromagnetic storage material.

11. The memory cell structure of claim 1, wherein at least a portion of the at least a first portion of the multiferroic material is in contact with the second electrode and the tunneling barrier material.

12. The memory cell structure of claim 11, wherein an outer edge portion of the at least a first portion of the multiferroic material is in line with an outer edge

portion of the tunneling barrier material.

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

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

a first multiferroic material having an inner edge portion in contact with a ferromagnetic storage material of the MTJ element;

a second multiferroic material having an inner edge portion in contact with the ferromagnetic storage material of the MTJ element; and

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

wherein the vertical access device includes a third and a fourth gate electrode, and wherein the memory cell includes at least a third multiferroic material in contact with the ferromagnetic storage material and located between the third and the fourth gate electrode.

14. The memory cell of claim 13, wherein the inner edge portion of the first multiferroic material is in contact with a first edge portion of the ferromagnetic storage material.

15. The memory cell of claim 13, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the first multiferroic material responsive to an applied voltage difference between the first gate electrode and the second gate electrode.

16. The memory cell of claim 13, wherein the inner edge portion of the second multiferroic material is in contact with a second edge portion of the ferromagnetic storage material.

17. The memory cell of claim 13, wherein the second multiferroic material is located between the first gate electrode and the second gate electrode.

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

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

a first multiferroic material having an upper surface portion in contact with a ferromagnetic storage material of the MTJ element;

a second multiferroic material having an upper surface portion in contact with the ferromagnetic storage material of the MTJ element; and

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

wherein the vertical access device includes a third and a fourth gate electrode, and wherein the memory cell includes at least a third multiferroic material in contact with the ferromagnetic storage material and located between the third and the fourth gate electrode.

19. The memory cell of claim 18, wherein an edge portion of the first multiferroic material is in contact with the second electrode.

20. The memory cell of claim 18, wherein the first gate electrode and the second gate electrode are configured to provide an electric field to the first multiferroic material responsive to an applied voltage difference between the first gate electrode and the second gate electrode.

21. The memory cell of claims 18-20, wherein an edge portion of the second multiferroic material is in contact with the ferromagnetic storage material.

22. The memory cell of claims 18-20, wherein the second multiferroic material is located between the first gate electrode and the second gate electrode.

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

a first ferromagnetic storage material in contact with a first multiferroic material;

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

a second ferromagnetic storage material in contact with a second

multiferroic material;

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

a third multiferroic material in contact with the first ferromagnetic storage material; and

a vertical access device having a first gate electrode and a second gate electrode, wherein the first multiferroic material and the second multiferroic material are located between the first gate electrode and the second gate electrode.

24. The memory cell of claim 23, including an antiferromagnetic material positioned between and in contact with the first and the second pinned ferromagnetic material, the antiferromagnetic material also positioned between the first and the second ferromagnetic material.

25. The memory cell of claim 23, including a fourth multiferroic material in contact with the second ferromagnetic storage material.

26. The memory cell of claim 25, wherein the first and the third multiferroic materials have a first ferroelectric polarizability, and wherein the second and the fourth multiferroic materials have a second ferroelectric polarizability that is different than the first ferroelectric polarizability.

27. The memory cell of claim 25, wherein the first multiferroic material is in contact with a first side surface of the first ferromagnetic storage material and the third multiferroic material is in contact with a second side surface of the first ferromagnetic storage material.

28. The memory cell of claim 27, wherein the second multiferroic material is in contact with a first side surface of the second ferromagnetic storage material and the fourth multiferroic material is in contact with a second side surface of the second ferromagnetic storage material.

29. The memory cell of claim 25, wherein the first multiferroic material and

the third multiferroic material are in contact with a top surface of the first ferromagnetic storage material.

30. The memory cell of claim 29, wherein the second multiferroic material and the fourth multiferroic material are in contact with a bottom surface of the second ferromagnetic storage material.

31. The memory cell of claim 23, wherein the first and the second multiferroic materials have different ferroelectric polarizabilities.

32. The memory cell of claim 31, including a top electrode in contact with the first ferromagnetic storage material and a bottom electrode in contact with the second ferromagnetic storage material.

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

providing, via an applied voltage difference between a first and a second gate electrode of a vertical access device, an electric field to a first multiferroic material in contact with a first ferromagnetic storage material; and

providing, via an applied voltage difference between a third and a fourth gate electrode of the vertical access device, an electric field to a second multiferroic material in contact with the first ferromagnetic storage material;

wherein at least one of the electric field between the first and the second gate electrode and the electric field between the third and the fourth gate electrode is sufficient to alter a magnetization direction of the first ferromagnetic storage material via exchange coupling between the first multiferroic material and the first ferromagnetic storage material.

34. The method of claim 33, wherein the electric field is sufficient to induce a switching of the magnetization direction of the first ferromagnetic storage material from a first configuration corresponding to a first data state of the STT memory cell to a second configuration corresponding to a second data state of the STT memory cell.

35. The method of claim 34, wherein the switching of the magnetization direction of the first ferromagnetic storage material includes switching the magnetization direction from at least one of:

a configuration parallel to a magnetization direction of a pinned ferromagnetic material coupled to the first ferromagnetic storage 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.

36. The method of claim 33, including subsequently providing a programming current through the STT memory cell element in a current perpendicular to plane (CPP) configuration.

37. The method of claim 36, including determining a data state of the STT memory cell subsequent to providing the programming current.

38. The method of claim 33, wherein the STT memory cell includes a stack of materials positioned between a bottom electrode and a top electrode, the stack comprising:

the first ferromagnetic storage material;

the first multiferroic material;

an antiferromagnetic material in contact with the pinned ferromagnetic material; and

a tunneling barrier material between the pinned ferromagnetic material and the antiferromagnetic material; and

wherein the first ferromagnetic storage material is in contact with at least one of the bottom electrode and the top electrode.

39. The method of claim 33, wherein the method includes:

providing, via the applied voltage difference between the first and the second gate electrode of the vertical access device, the electric field to a second multiferroic material in contact with a second ferromagnetic storage material;

and

wherein the electric field is sufficient to alter a magnetization direction of the second ferromagnetic storage material via exchange coupling between the second multiferroic material and the second ferromagnetic storage material.

40. The method of claim 39, wherein the STT memory cell includes a stack of materials positioned between a bottom electrode and a top electrode, the stack comprising:

the first ferromagnetic storage material and the second ferromagnetic storage material;

the first multiferroic material and the second multiferroic material;

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

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

an antiferromagnetic material in contact with and between the first pinned ferromagnetic material and the second pinned ferromagnetic material; and

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.

41. The method of claim 39, wherein the STT memory cell is configured to store at least two data bits.

42. The method of claim 39, wherein the first multiferroic material and the second multiferroic material have different ferroelectric polarizabilities.

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

a STT stack including:

a pinned ferromagnetic material in contact with an antiferromagnetic material;

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

a multiferroic material in contact with the ferromagnetic storage material, wherein the multiferroic material is continuous around the ferromagnetic storage material; and

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

a third electrode and a fourth electrode, wherein at least a first portion of the multiferroic material is located between the third and the fourth electrode.

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

a first ferromagnetic storage material in contact with a first multiferroic material;

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

a second ferromagnetic storage material in contact with a second multiferroic material;

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

wherein the first multiferroic material is continuous and surrounds the first ferromagnetic storage material, and wherein the second multiferroic material is continuous and surrounds the second ferromagnetic storage material; and

a vertical access device having a first gate electrode and a second gate electrode, wherein the first multiferroic material and the second multiferroic material are located between the first gate electrode and the second gate electrode.