

CLAIMS

1. A magnetic logic device comprising:
two magnetic elements,
5 wherein the magnetic logic device is configured, for each of the two magnetic elements, to have a magnetisation state with a perpendicular easy axis, and configured to switch the magnetisation state in response to a spin current generated in the magnetic element in response to a write current applied to the magnetic element; and
a conductive element coupled to the two magnetic elements and arranged at least
10 substantially perpendicular to the two magnetic elements,
wherein the magnetic logic device is configured to generate, as an output, a Hall voltage across the conductive element in response to a respective read current applied to each of the two magnetic elements, wherein a magnitude of the Hall voltage is variable, depending on a direction of the magnetisation state of each of the two magnetic elements and a direction of the
15 respective read current applied to each of the two magnetic elements, for the magnetic logic device to provide outputs corresponding to one of a plurality of logical operations.
2. The magnetic logic device as claimed in claim 1, wherein in one mode of operation, for each of the two magnetic elements,
20 the direction of the respective read current is fixed, and the magnitude of the Hall voltage is variable in response to a change in a direction of the write current applied to the magnetic element to change a polarity of the spin current to switch the magnetisation state.
3. The magnetic logic device as claimed in any one of claims 1 or 2, wherein in a further
25 mode of operation, for each of the two magnetic elements,
the magnetisation state is maintained, and the magnitude of the Hall voltage is variable in response to a change in the direction of the respective read current applied to the magnetic element.
- 30 4. The magnetic logic device as claimed in any one of claims 1 to 3, further configured to skew the magnetisation state of each of the two magnetic elements away from the perpendicular

easy axis for the magnetic element to switch the magnetisation state in response to the spin current.

5. The magnetic logic device as claimed in claim 4, configured to skew the magnetisation state by generating a magnetic field across the two magnetic elements using an electromagnet.

6. The magnetic logic device as claimed in claim 4, configured to skew the magnetisation state by disposing a conductive field bias line adjacent to the two magnetic elements, and the magnetic logic device is configured for the conductive field bias line to generate an Oersted field to interact with the two magnetic elements.

7. The magnetic logic device as claimed in claim 6, wherein, for each of the two magnetic elements, the magnetic element is configured to switch the magnetisation state in response to the spin current and the Oersted field, wherein the direction of the magnetisation state after switching is dependent on a polarity of the write current and a direction of the Oersted field.

8. The magnetic logic device as claimed in claim 4, wherein each of the two magnetic elements comprises a ferromagnetic layer, and the magnetic logic device is configured to skew the magnetisation state by forming each of the two magnetic elements with an antiferromagnetic layer or an in-plane ferromagnetic layer for exchange coupling with the ferromagnetic layer.

9. The magnetic logic device as claimed in claim 8, wherein, for each of the two magnetic elements, the magnetic element further comprises a non-magnetic material between the ferromagnetic layer and the antiferromagnetic layer or the in-plane ferromagnetic layer.

10. The magnetic logic device as claimed in claim 4, configured to skew the magnetisation state by, for each of the two magnetic elements, arranging an electrode and a dielectric layer between the electrode and the magnetic element, and, wherein the magnetic logic device is configured so that, in response to a voltage applied to the electrode, an electric field is generated in the dielectric for tuning a magnetic anisotropy of the magnetic element.

11. The magnetic logic device as claimed in any one of claims 1 to 10, further comprising a rectification circuit electrically coupled to the conductive element to rectify the Hall voltage.
- 5 12. The magnetic logic device as claimed in any one of claims 1 to 11, wherein the magnetic logic device is configured to provide the outputs corresponding to at least one of AND, NOR, XNOR, XOR, NIMP, and converse NIMP logical operations.
13. A circuit comprising:
- 10 a first magnetic logic device and a second magnetic logic device electrically coupled to each other,
- wherein the first magnetic logic device is as claimed in claim 12 to provide the outputs corresponding to an XOR logical operation, and
- wherein the second magnetic logic device is as claimed in claim 12 to provide the
- 15 outputs corresponding to an AND logical operation.
14. A method for controlling a magnetic logic device comprising two magnetic elements and a conductive element coupled to the two magnetic elements and arranged at least substantially perpendicular to the two magnetic elements, wherein the magnetic logic device is
- 20 configured, for each of the two magnetic elements, to have a magnetisation state with a perpendicular easy axis, the method comprising:
- skewing the magnetisation state of each of the two magnetic elements away from the perpendicular easy axis for switching the magnetisation state;
- for each of the two magnetic elements, applying a write current to the magnetic element
- 25 to generate a spin current in the magnetic element to switch the magnetisation state; and
- applying a respective read current to each of the two magnetic elements for the magnetic logic device to generate, as an output, a Hall voltage across the conductive element, wherein a magnitude of the Hall voltage is variable, depending on a direction of the magnetisation state of each of the two magnetic elements and a direction of the respective read
- 30 current applied to each of the two magnetic elements, for the magnetic logic device to provide outputs corresponding to one of a plurality of logical operations.

15. The method as claimed in claim 14, wherein, in one mode of operation, for each of the two magnetic elements, the direction of the respective read current is fixed and the method comprises changing a direction of the write current applied to the magnetic element to change a polarity of the spin current to switch the magnetisation state, wherein the magnitude of the Hall voltage is variable in response to the change in the direction of the write current.

16. The method as claimed in claim 14 or 15, wherein, in a further mode of operation, for each of the two magnetic elements, the magnetisation state is maintained and the method comprises changing the direction of the respective read current, wherein the magnitude of the Hall voltage is variable in response to the change in the direction of the respective read current.

17. The method as claimed in any one of claims 14 to 16, wherein skewing the magnetisation state of each of the two magnetic elements away from the perpendicular easy axis comprises generating, using an electromagnet, a magnetic field across the two magnetic elements.

18. The method as claimed in any one of claims 14 to 16, wherein skewing the magnetisation state of each of the two magnetic elements away from the perpendicular easy axis comprises applying a field current to a conductive field bias line adjacent to the two magnetic elements to generate an Oersted field to interact with the two magnetic elements.

19. The method as claimed in claim 18, further comprising changing a direction of the field current to change a direction of the Oersted field.

20. The method as claimed in any one of claims 14 to 16, wherein skewing the magnetisation state of each of the two magnetic elements away from the perpendicular easy axis comprises, for each of the two magnetic elements, applying a voltage to an electrode arranged adjacent to the magnetic element to generate an electric field in a dielectric arranged between the electrode and the magnetic element for tuning a magnetic anisotropy of the magnetic element.

21 The method as claimed in any one of claims 14 to 20, further comprising rectifying the Hall voltage.

5 22. The method as claimed in any one of claims 14 to 21, further comprising operating the magnetic logic device to provide the outputs corresponding to at least one of AND, NOR, XNOR, XOR, NIMP, and converse NIMP logical operations.

23. A method for controlling a circuit comprising:

10 operating a first magnetic logic device of the circuit according to the method as claimed in claim 22 to provide the outputs corresponding to an XOR logical operation; and
operating a second magnetic logic device of the circuit according to the method as claimed in claim 22 to provide the outputs corresponding to an AND logical operation,
wherein the first magnetic logic device and the second magnetic logic device are
15 electrically coupled to each other.