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First demonstration of highly reliable spintronics devices

[Abstract] The research group of Professor Hideo Ohno of Center for Spintronics Integrated Systems and Research Institute of Electrical Communication of Tohoku University together with Kyoto University and NEC Corporation (NEC) demonstrated the world's first three-terminal spintronics device that is as highly reliable as existing semiconductor technologies. They optimized a structure of nanometer-sized magnetic film and achieved (1) sufficient operation stability and high endurance and (2) availability under a broad range of environments such as temperature and magnetic field. In addition, they confirmed (3) 10-years' non-volatile data retention at a temperature of 150°C, which is a common specification for automobile application. In system-LSI, which is a core device of digital equipment, considerable increase in standby power has grown into a serious problem in recent years. The obtained results show that the developed technology can provide a new value of "zero standby power" to the system-LSI without degrading the reliability or convenience of existing technology. With this device technology, the developments toward practical use are expected to be accelerated.

[Background]

System-LSI has for decades played a principal role in enhancing the performance of digital electronics equipment such as personal computers and mobile phones. However, large obstacles stand in the way of further progress; the biggest one is an increase in consumption power during standby. Recently, spintronics technologies have attracted a great deal of attention as a candidate to solve this problem. Spintronics elements can retain the data, i.e. nonvolatile, resulting in zero standby power because they utilize a magnetic property for data storage, whereas semiconductor memory cells which are used in the existing system-LSI miss the stored data when the power was cut off, i.e. volatile. These spintronics elements are categorized into two-terminal and three-terminal types. The three-terminal spintronics element is suitable for a high-speed memory and nonvolatile element in high-speed logic circuit (*1) because write and read current paths differ from each other.

Current-induced domain wall motion (*2), which has gathered considerable attention as a novel technology in spintronics, is a phenomenon in which a magnetic polarity can be reversed by introducing a current into the fine magnet itself. It is easily applied to the above three-terminal spintronics element, and the element using it can adapt to the leading edge LSI generation due to the excellent scalability (*3). In the previous research and development, basic operation of a memory device has been demonstrated in the three-terminal element with current-induced domain wall motion.

[Research issue]

The spintronics device can provide a new value of "zero standby power" with high-speed operation, which is impossible for existing semiconductor technologies as mentioned above. On the other hand, for practical use in the market of system-LSI, the reliability and convenience of existing technology must not be degraded. For example, (1) operation stability and endurance in the existing semiconductor device are high enough to be used for 10 years, and equivalent features are required in the spintronics device. Similarly, (2) the spintronics device has to operate normally under a broad range of temperatures and magnetic field environments in which the existing semiconductor devices have been used. In addition to them, (3) it should be demonstrated that the element has 10-years' retention property without power supply, which is impossible in existing technology. Then, the practical use of the spintronics element becomes a real possibility.

[Technical method and achievement]

A group consisting of Tohoku University, Kyoto University, and NEC investigated in detail the stack structure of a nanometer-sized magnetic film composed of cobalt and nickel that acts as information storage in the present current-induced domain wall motion device. Then, they demonstrated that the integrated device with the developed film can provide the new value of nonvolatility, which is a unique feature of the spintronics element, while maintaining characteristics equivalent to the existing semiconductor technologies, as described below:

First, (1) sufficiently high stability of operation and endurance required for the three-terminal device were confirmed. Then, (2) no variation in the writing characteristics was observed under an external temperature of -200 ~ 150°C and external magnetic field of ±50 Oersted (*4) . In addition, (3) it was confirmed that the developed element has 10-years' retention property under a temperature of as high as 150°C; this is the highest temperature required for the LSI devices for automobile application. This is the first time these three requirements have been satisfied simultaneously. Furthermore, they also confirmed these properties in a prototype chip where the spintronics elements were formed on an integrated circuit.

[Significance of research]

The high reliability of the three-terminal device elucidated here can diminish a load of circuit system such as error correction and accordingly the way to an application of spintronics logic circuit was opened.

Tohoku University, Kyoto University, and NEC will announce their latest results on June 12 at the 2012 Symposium on VLSI Technology (June 12-15, Hawaii, USA).

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Notes:

(*1) Nonvolatile element in high-speed logic circuit

A temporal storage circuit is connected to a logic circuit that processes information in LSI. The representative example is a flip-flop device. If this circuit become nonvolatile, it will be possible to drastically reduce the consumption power by controlling the power supply frequently.

(*2) Current-induced domain wall motion

Magnetic properties of magnets originate from a magnetic moment of electron. When one looks at the inside of the magnets microscopically, there are a number of domains where the moments are aligned in one direction, called magnetic domains. The boundary region of the two magnetic domains with a moment pointing different directions is called the magnetic domain wall.

Current-induced domain wall motion is a phenomenon in which the magnetic domain wall is displaced in an opposite direction to the current, i.e. same direction to electron flow when current passes through the domain wall. It was theoretically predicted by L Berger in 1978, and experimentally demonstrated for the first time by research groups of Professor Teruo Ono of Kyoto University and of Professor Hideo Ohno of Tohoku University in 2004.

(*3) Scalability

Scalability is the ability to enhance a property with reducing device size. LSI technology has had its performance enhanced for several decades due to its good scalability, but it is beginning to face physical limits.

(*4) Oersted (abbreviated as Oe)

Oersted is the unit of magnetic field. 1 Oe is defined as a magnetic field strength at a position of 1-cm-away from a magnetic pole of 1 emu/cm, or that in the center of closed circuit with a radius of 1 cm and carrying a current of $1/2\pi$ A. The magnetic field generated from geomagnetism is about 0.5 Oe.