Nonvolatile Programmable Spin-Logic Gates Show Potential in Reconfigurable Computing

Researchers at Siemens AG and the University of Bielefeld, Germany, have made programmable spin-logic gates based on spin-dependent tunneling (STD) elements. The SDT elements form the spin-logic gates, allowing programmable logic operations.

For reconfigurable computing using highly magnetoresistive thin-film magnetic structures, it is essential that a programming operation be performed rapidly and with no practical limitation of programming cycles. In spin logic, the programming information (i.e., the logic inputs and outputs) is nonvolatile and power consumption is low. The researchers chose a tunneling system because it exhibits good readout-voltage levels for submicrometer elements and compatibility to nonvolatile memory. The major challenges of such a tunneling system are that it needs a homogeneous device-fabrication process and homogeneous tunneling-current distribution or a tunneling barrier. The researchers showed that such requirements could be met down to an area of 0.6 μm^2 per SDT element.

Using a seven-mask lithography process, R. Richter and colleagues fabricated an IrMn/CoFe/Ru/CoFe/Al_2O_3/NiFe tunneling structure, in which the artificial antiferrimagnet hard subsystem, CoFe (2.0 nm)/Ru (0.9 nm)/CoFe (3.0 nm), was exchange-biased to the antiferromagnet IrMn. As reported in the February 18 issue of *Applied Physics Letters*, field-programmable gate arrays (FPGAs) were constructed from three-input field-programmable spin-logic gates (in order to compare with semiconductor-based FPGAs). Each gate consisted of six SDT elements. A current in a switch line generated a magnetic field to switch the soft magnetic NiFe layer and, hence, the corresponding SDT element between its high- and low-resistance states. A clock line ran on top and perpendicular to the switch line. These two lines were electrically isolated from each other and from the SDT elements. The device was typically operated at a tunneling current of 5 µA with a corresponding voltage of ~300 mV across each SDT element. The voltage across a switch line led to a current and, hence, to a magnetic field at the location of the selected SDT element.

In the six-element configuration, three elements were chosen as reference bits, and the other three served as logic input bits. The voltages defining the inputs Boolean 0 and Boolean 1 were chosen such that the corresponding magnetic fields were sufficient to switch the soft magnetic layer of any selected SDT element. Thus, programming was as fast as performing a logic operation. Additionally, the researchers reported no limitation of programming cycles.

The researchers showed the feasibility of a hybrid field-programmable spin-logic gate based on SDT elements in steady-state and clocked operation. They achieved working hybrid spin-logic gates with higher integration density and the possibility of more than three inputs. The programming information and the logic inputs/output were nonvolatile. The researchers said that FPGAs based on spin-logic gates hold promise for reconfigurable computing.

SHIMING WU

Light-Induced Transformation Changes Gallium Conductivity

A research group led by Nikolay Zheludev at the University of Southampton has observed a new mechanism of photoconductivity in α-gallium wherein a phase transition induced by light leads to a metastable phase of different conductivity. As reported in the February 18 issue of *Applied Physics Letters*, the researchers believe that the light-induced transformation was made possible by surface confinement of the gallium, which may have erased the distinction between first- and second-order phase transitions.

The researchers created the confined interface by sandwiching a small drop of liquid gallium between a cover glass and a glass substrate with silver electrodes spaced 250 µm apart. The drop of liquid gallium was placed between the electrodes. Pressure on the cover glass flattened the drop so that it spanned the electrodes. Once solidified, the gallium "bridge" across the electrode gap was ~50 µm wide and 1 µm thick. A 514-nm argon laser induced the conductivity change. The researchers focused the beam on a 30-µm spot and mechanically modulated its intensity at 200 Hz. In addition, a small dc current source and a lock-in detector were used to measure the change in conductivity. The researchers controlled the gallium temperature by using a Peltier heat pump in thermal contact with the glass substrate on which the silver electrodes were deposited.

While increasing the laser power, the researchers held the temperature at a constant 20°C, which is below gallium's melting point. The light-induced conductivity change increased linearly with increasing power below 4 mW, and then increased rapidly with increasing power from about 4 mW to 7.5 mW, where the conductivity saturated. The researchers also used constant laser power while scanning the temperature across gallium's bulk melting point (29.8°C). The resulting data showed a hysteresis in the photoconductivity signal with temperature. The researchers concluded that their sample underwent "surface-assisted light-induced metallization of α-gallium." The researchers said that this material property has the potential for applications in optically fast broadband photodetectors.

PAMELA JOHNSON

Laser-Induced Damage on CVD Diamond Measured by Photoacoustic Technique

Researchers in the Department of Electrical Engineering at the National Tsinghua University, Taiwan, and at Brookhaven National Laboratory have measured the laser-induced damage threshold (LIDT) at the surface of bulk chemical-vapor-deposited (CVD) diamond. The LIDT was measured by amplifying the acoustic wave generated by the breakdown of the substrate under laser irradiation. The researchers said that this method enables a more accurate determination of substrate breakdown than other techniques currently employed in the field. The researchers found that the LIDT for the diamond surface was higher than that for other common CO_2 laser optical materials under the same conditions. The exact improvement depended on the length of the laser pulse. These results, they said, indicate that CVD diamond is a promising material for CO_2 laser optics.

As reported in the February 1 issue of *Optics Letters*, lead author A.C. Chiang and colleagues used CVD diamond, ZnSe, and Ge window flats polished to an optical finish. The laser pulses were generated by a hybrid transversely excited atmosphere single longitudinal mode CO_2 oscillator and amplifier. The oscillator generated 100-ns pulses; 200-ps pulses were generated by reflection of a portion of the 100-ns pulse from an optically gated Ge switch. LIDT is defined as the minimum laser fluence (energy per unit area) needed to damage the surface of the substrate. The LIDT for irradiation with 200-ps pulses was measured by placing the substrate in the path of the laser beam and then varying the attenuation of the beam until laser-induced dielectric breakdown was detected. The LIDT for irradiation with 100-ns pulses was measured by slowly moving the substrate toward the waist (the thinnest part) of an unattenuated laser beam until damage was detected. The error in the LIDT was determined from the variation in the laser power under the con-