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Plasmonic modulator driven by phase-transition of GST superlattice

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Abstract

We propose a new design of plasmonic modulator using phase transition of $[(GeTe)_2/(Sb_2Te_3)_1]_{40}$ superlattice (GST-SL) driven by applying electrical pulses. While the structure changes from a RESET (high-resistive) phase to a SET (low-resistive) phase, the optical and the electrical property change. When we apply electrical pulses to a multiple layer device including GST-SL, a reduction of resistivity is observed for electric voltages above a threshold. Moreover, the resistivity shows a gradual increase while applying another series of electrical pulses. These reduction and the following recovery of the resistivity induced by electrical pulses are interpreted as RESET-SET reversible phase transitions of the GST-SL.

1. Introduction

$[(GeTe)_2/(Sb_2Te_3)_1]_{40}$ superlattice (GST-SL), which consists of alternative stacks of GeTe layer and Sb_2Te_3 layer, functions as a phase-change material [1]. The phase transition of GST-SL from high-resistive phase (RESET) to low-resistive phase (SET) is caused by applying electrical pulses exceeding a certain threshold voltage. The reversed process is also performed by applying pulses with higher voltages. GST-SL possesses an advantage over the $Ge_2Sb_2Te_5$ alloy, which is widely used for recording layers of optical discs and for phase-change random access memory (PRAM) cells, particularly in the reduction of energy consumption during phase transition, fast switching time, and large contrast of optical property [2].

Surface plasmons are collective oscillations of free electrons of metal. When plasmon waves propagate along a metal-insulator interface, the electromagnetic field is localized at the interface. Therefore, sub-wavelength scale modulating devices, in other words plasmonic modulators, can be realized by using plasmon waves as the carrier of information [3-5].

In this paper, we report a new design of a plasmonic modulator based on phase transitions of the GST-SL driven by external electrical pulses.

2. Experiment

Fabrication of the device

Fig. 1(a) shows a cross-sectional view of the device. To fabricate the device, we applied maskless photolithography processes for several times. First, SiO_2 (80 nm, sacrifice layer), Si_3N_4 (80 nm), ITO (240 nm), Au (80 nm) and Cr (8nm, adhesion layer) were sputtered on a 20 mm-square Al_2O_3 substrate. It is noted that the ITO layer have a role of the electrode as well as the optical waveguide. Next, photo resist (AZ5214E) was spin coated to expose rectangular shapes (5 × 5 ~ 30 μm) by using the maskless lithography system. Then, a reactive ion etching was applied to remove uncovered parts of the SiO_2 and the Si_3N_4 layers. After a liftoff process, a GST-SL layer (80 nm) was deposited by RF sputtering. To make embedding structure of GST-SL, the second maskless lithography and etching processes were carried out. Afterward, the third maskless lithography process was performed to place an ITO layer (40 nm), which works as the upper electrode as well as for protecting the GST-SL from oxidation. Finally, we etched both the Si_3N_4 and the lower ITO layers by using a focus ion beam etching to make the input and the output slit structures. These slit structures have a role of light-plasmon wave coupler. Fig. 1 (b) shows a SEM image of the fabricated device.

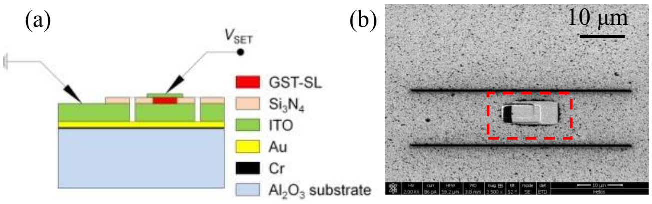

Fig. 1 (a) The cross-sectional view of the device and measurement setup. (b) SEM image of fabricated device. Red dashed square indicates embedded structure of GST-SL.

Electrical pulse induced phase transition

To induce phase transitions of the GST-SL, sequences of electrical pulses (pulse width: 1000 ns) were applied to the device between the upper ITO layer and the lower ITO layer. Each sequence included 50 electrical pulses with the repetition frequency of 250 kHz. The voltage of the pulse (V_{SET}) was initially set at 0.5 V, and was gradually increased to 3.0 V or 3.5 V with an increment step of 0.05 V or 0.06 V, respectively. While applying each voltage pulse, the electric current that flows through the device was measured for monitoring the variation of resistance (R_{read}).

3. Results and discussion

Fig. 2 shows resistance-voltage curves obtained by applying sequences of electrical pulses for four times. The ranges of pulse voltages are 0.5 V ~ 3.0 V (1st, 2nd) and 0.5

V ~ 3.5 V (3rd, 4th), respectively. At the 1st sequence (red circle), the initial resistance was ~ 11 kΩ and abruptly decreased to ~ 2.5 kΩ when the voltage reached to 2.95 V. This behavior is interpreted as the RESET (high-resistive) to the SET (low-resistive) phase transition of the GST-SL. Once the resistance decreases, it keeps the low resistivity (SET) phase while applying the additional sequence of pulses, as is shown as the blue line in the Fig. 2. However, at the 3rd sequence (green triangle), the resistance gradually increased for the voltages over 2.54 V. After that, the initial resistance of the 4th sequence (yellow diamond) retuned to ~ 12 kΩ. The recovery of the resistivity amounted to the initial state of the GST-SL (~ 11 kΩ) suggests that the SET to RESET phase transition occurred. Moreover, in the 4th sequence, the resistance decreased suddenly when the voltage of the electrical pulse was increased to ~ 2.72 V, suggesting another RESET to SET phase transition was induced. These results suggest reversible RESET-SET phase transitions of the GST-SL embedded in the plasmonic waveguide are actualized.

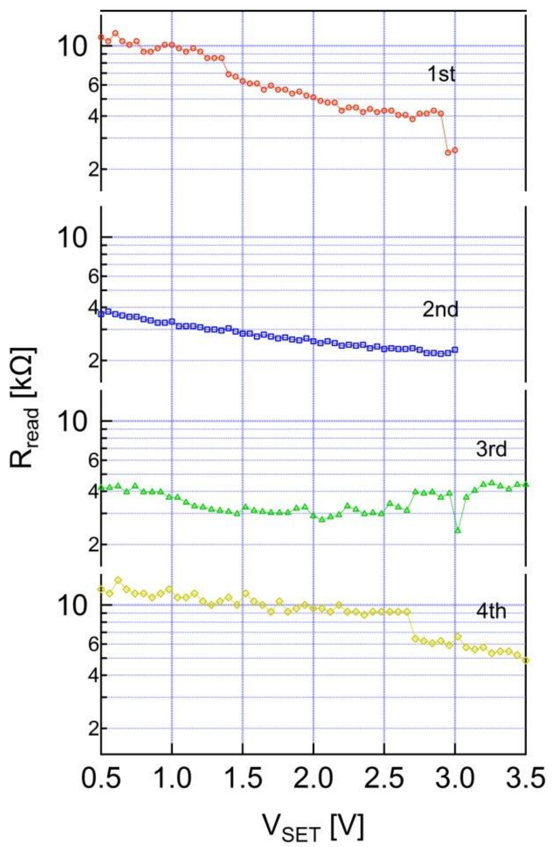

Fig. 2 Resistance-voltage curves. Red circles, blue squares, green triangles and yellow diamonds are 1st, 2nd, 3rd and 4th sequence, respectively.

3. Conclusions

We fabricated a plasmonic modulator using the phase transition of GST-SL. To insert the GST-SL in the multi-layered structure, we use several process of maskless photolithography.

To induce the phase transition, we applied sequences of electrical pulses to the device including GST-SL. When the voltage reached to 2.95 V, the resistance abruptly decreased. This behavior corresponds to the RESET to SET phase transition of the GST-SL. In addition, the resistance of GST-SL recovered after applying several pulses that can be interpreted as the SET to RESET phase transition. Our result suggests an availability of a new plasmonic modulating device using GST-SL.

Acknowledgements

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