Enhanced Optical Readout in Resistive Memory Through Plasmonic Amplification

(Student Paper)

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ABSTRACT

An electrically writable resistive switch with optical readout capability is proposed with a high extinction ratio of 16 dB utilizing plasmonic amplification in InGaP. The proposed device operating at 1550 nm wavelength shows an optical gain of 2.4 dB. The optical readout is less error prone and has low energy consumption then it's electrical counterpart. The high index layer, bottom electrode material, provide dual benefits: low loss waveguiding of light and electrical rectification. The device can find applications in optical interconnects, optical modulation, memory and neuromorphic computations.

Keywords: resistive switch, electrical pumping, optical memory, intensity modulator, hybrid plasmonic, integrated photonics.

1. INTRODUCTION

The resistive memory is promising contenders for ultralow-energy electronic devices [1][2]. Most of the electronic device suffers from heat losses which affect the overall performance of the electronic device. Photonic devices can be used to tackle with heating losses and to improve high bandwidth operation. But these devices have a large footprint area due to the diffraction limit of light. Surface plasmon polariton (SPP) can be used to guide light much beyond diffraction limitations but has high ohmic losses. The coupling of SPP and optical mode can reduce these plasmonic losses resulting in hybrid plasmonic waveguide [3][4]. The large interaction of light-matter in the plasmonic waveguide can be used for optical readout of these resistive switches to save per bit energy consumption [5]. The optical readout is less error-prone than its counter electrical readout. An optical resistive switch with an improved optical extinction ratio is proposed using plasmonic amplification. The device is electrically writable, and its resistance state is read using the optical signal. The high index InGaP is used to provide amplification to the propagating hybrid plasmonic mode in the 10-nm of SiO_2. The three-layered design provides multifold benefits: low loss waveguide for 1550-nm wavelength and metal-insulator-semiconductor device provides good rectification for fabrication in a 3D stack. The device has the application in neuromorphic computing [6], optical interconnects and optical switches.

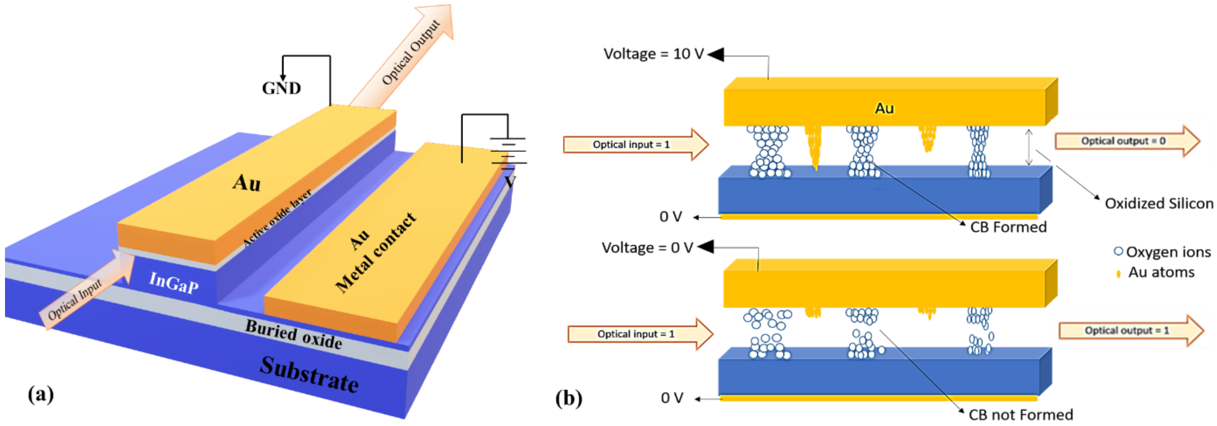

Figure 1. (a) The proposed schematic of the hybrid plasmonic waveguide with a restive switching effect. (b) Resistive switching mechanism with gold diffusion and its effect on the optical signal.

2. DEVICE DESIGN AND WORKING

The proposed resistive memory device consists of a silicon oxide layer of 10-nm sandwiched between the two electrodes i.e. top electrode gold 100-nm and bottom electrode InGaP. Another metal contact is provided over the extended layer of InGaP providing ohmic contact to the high index semiconductor layer. The potential is applied between the two metal contacts, which forces them to break the SiO_2 into silicon and oxygen ions. With the influence of the external electric field and the ion concentration gradients, oxygen ions try to align themselves to form Conduction Bridge (CB). After 7 volts the CB is fully formed providing low resistance state to the device resulting in the increment of local thermal temperature, which in turn results in the diffusion of the metal ions into the active layer of SiO_2 where the maximum intensity of the light resides. The hybrid plasmonic mode that propagates in the device has a maximum intensity in the active layer of 10-nm SiO_2. After the formation of CB, the metal-ions start to diffuse into the SiO_2 increasing the metal absorption hence low intensity at the output of the device.

2.1 ELECTRICAL CHARACTERISTICS

Experimentally the device is realized using silicon as the high index layer. The device changes its SET voltage with the change in the temperature, inset of fig2(a). As the temperature increases the potential energy required to break the oxygen ions reduces leads to a lower SET voltage. The device has shown reliable results up to 170^{o}C. The I-V characteristics have shown a sharp change in current value is 7 volts is reached at room temperature. The device is volatile in nature, reset itself when 0 volts are applied. The current difference of 0.5 µA is measured between high resistance state (HRS)and low resistance state (LRS), fig.2(a). The good rectification property of the device makes it realizable for fabrication in the 3D stack of switches/memory. The change in the set value with change in local temperature makes the device suitable to use in neuromorphic computation as weighted synapses.

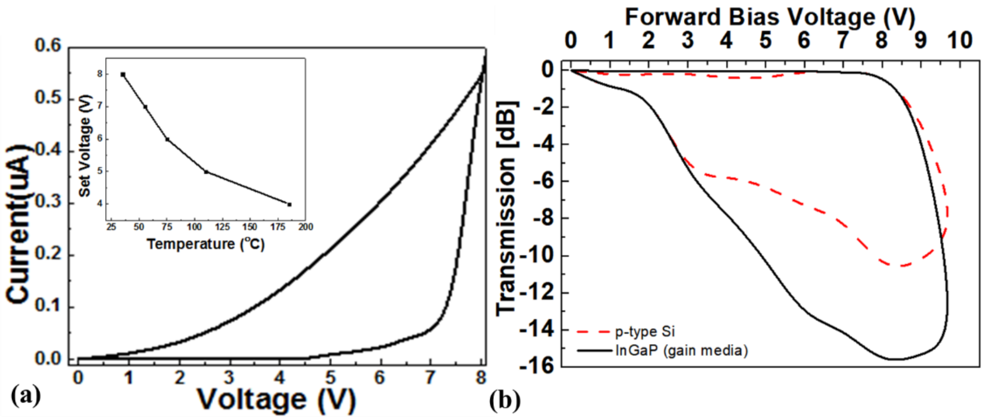

Figure 2 (a) Measured IV characteristics of the resistive switch with p-type silicon showing set and reset state inset shows the effect of temperature on the set voltage (b) Optical readout transmission of with silicon and InGaP.

2.2 OPTICAL CHARACTERISTICS

The text High optical intensity is observed when the device is electrically off (HRS). After a voltage of 8 volts, the silicon dioxide atoms break down into oxygen and silicon ions, which aligned themselves in the direction of applied electrical field forming conduction bridge (CB) i.e. a low resistance path to electrical current, hence electrical on state. Sudden large current flow increases the local temperature very high resulting in top electrode, Au, atoms diffusion in the 10-nm of dielectric active layer. These diffused atoms of metal hinder the path of light and hence 16 dB less intensity of the light at output. The propagating hybrid plasmonic mode suffers from high metallic losses even in the HRS cycle. To amplify the plasmonic mode the high index layer is replaced with the gain media i.e. InGaP. The gain media provides low loss in the HRS cycle by providing extra electrons to the SiO_2 for the SPP propagation in the waveguide. Whereas in the LRS the metal diffusion controls the amount of absorption which leads to the low transmission with a 16dB of clear extinction ratio is observed, fig.2(b). The difference between the transmission with and without gain media shows a clear difference in the extinction ratio. The device with InGaP has also shown (simulated) an optical gain of 2.39 dB of intensity only in the set cycle (HRS). The clear hysteresis in the optical intensity makes the device less error-prone and useful for high bandwidth operation with low energy consumption

3. CONCLUSIONS

The proposed scheme shows an enhancement in the optical readout of the resistive switch state by providing plasmon amplification with gain media. The gain media improves the transmission in high resistance state (set cycle) while the transmission in LRS is only affected by metal ion diffusion resulting in a high extinction ratio of 16 dB. The proposed device has shown an optical gain of 2.4 dB of intensity in the set cycle (HRS). Compared to Si as InGaP has shown an enhancement of 6 dB in optical extinction ratio. The optical readout of the resistive switch makes it less error prone compared to electrical readout. The electrical energy consumption of the device is much less compared to electrical readout. The device has the potential to be used as compact optical intensity modulator. The results can be useful in realizing integrated nanophotonic platform for device applications in optical interconnects and memory.

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