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Fabrication of vertically positioned silicon on insulator photo-activated modulator

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Abstract

In this paper we present the fabrication process and the experimental proof of principle of a vertical Silicon On Insulator Photo Activated Modulator (vertical SOI-PAM). In this device the information is electronic while the modulation command is photonic. Since photon illumination generates free charges and current, the information channel should be isolated by combination of metal and oxide layers in order to avoid cross-talk. However photo-generated charges are capable of closing the channel by inducing changes in the space charge layers on both sides of the oxide. The device is a vertical structure of n-type silicon resistor on oxide insulator above a p-type silicon substrate. The photonic modulation command is applied by top illumination of a specially etched V-groove in the p-type substrate in the vicinity of the resistor.

Keywords: Electro-optical devices; Photonic integrated circuits; Modulator; Silicon photonics; Fabrication

1. Introduction

It is well known that integrated circuits speed is mainly limited by built-in resistances and capacitances in its I/O's. The recent attempts to overcome this limitation lead to hybrid electro-optical modules and devices [1]. The natural advantage of light consists in its high propagation velocity, reduced cross talk and the absence of electrical noise [2]. Such devices can operate at very low operational power and are capable of parallel processing [3].

Another important advantage of realizing such devices on a silicon chip is the compatibility with the standard microelectronic processing of devices. Large variety of optical modulators on silicon chips has been previously proposed [4,5]. The main disadvantage in such modulators, however, is their relatively large dimensions. Indeed most switching devices based on silicon, consist of relatively long waveguide structures such as a Mach-Zehnder interferometer [6–8], large non-planar modulating structure [9] or resonators with a high Q factor like a ring resonator coupled to a waveguide [9,10], which require also use of high power external lasers.

In this paper we present the structure and fabrication process of a novel device which we called SOI-PAM for Silicon On Insulator Photo-Activated Modulator. This is a new type of semiconductor device that is controlled by light and is expected to overcome the currently existing speed barrier of silicon based technology. The principle of the physical operation of this device was demonstrated before on the basis of regular MOS capacitors [11].

Like in a MOSFET or a JFET the information current flows through a silicon channel that is limited by two

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terminals (source and drain). However, unlike the MOSFET, the channel is separated from the silicon substrate by an insulating oxide layer in order to avoid cross-talk with the photo-generated current. The novelty of our device is that the control command is applied via external illumination. Thus, the device response time can be reduced since the semiconductor *RC* time constant is no longer relevant in the gate and the basic response rate limitation is related to the photo-generation rate and to the velocity of the free carriers in silicon.

The fabrication process that is proposed in this paper is for vertical structure of the SOI-PAM. Such an orientation and design can simplify the fabrication process and increase its yield.

The paper is constructed as follows: in Section 2 we present a brief description of the device operation modes. In Section 3 we present the fabrication process of the prototype device. In Section 4 we experimentally characterize the fabricated chip and in Section 5 we conclude the paper.

2. Device operation modes

2.1. The SOI-PAM without illumination—open (ON) state

As depicted in Fig. 1(a) the device consists of an information channel (n-type silicon) supplied with source and drain potentials which are denoted as V_S and

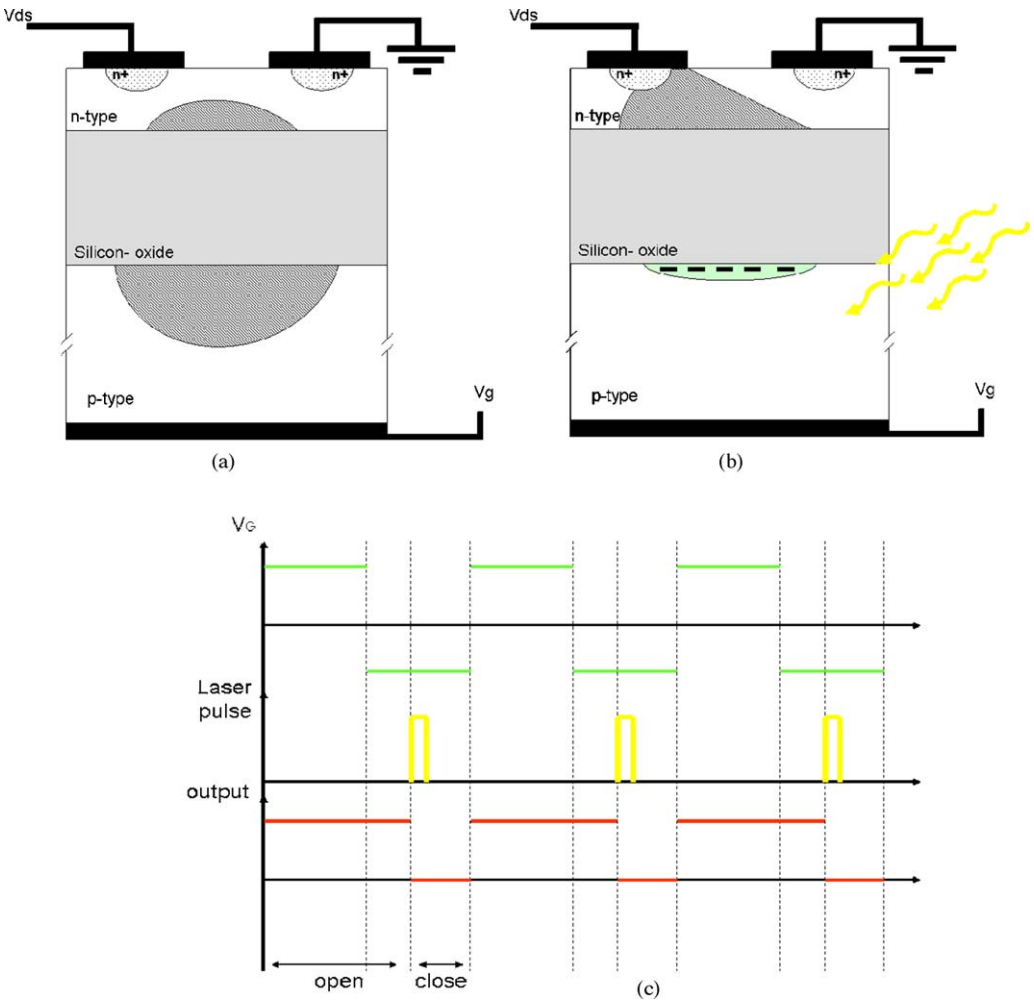

Fig. 1. Schematic cross section of the device (a). without illumination and negative V_g. The n-type channel is still opened. (b) With selective illumination of the p-type substrate and negative V_g, the photo-generated inversion layer increases the depletion layer in the channel and eventually close it. (c) Timing diagram and the control scheme of the device. Modulating the bottom gate potential V_G and applying laser pulse will modulate the channel current.