Digest of Tech. Papers The 6th Conf. on Solid State Devices, Tokyo, Sep. 1974

A2-3 Optical Waveguide with Nonvolatile Conductor-Insulators-Semiconductor Memory Structures on a Silicon Substrate

Y.Komiya, T.Sakamoto, E.Suzuki and Y.Tarui
Electrotechnical Laboratory
Tanashi, Tokyo

Combination of a thin film optical circuit[1] with semiconductor substrate will be one of important technology in future. For the first trial, a thin optical waveguide including nonvolatile memory is combined with silicon planar device. The purpose of this paper is to describe the fabrication method and propagation characteristics of Ta_2O_5-SiO_2-Si optical waveguides and to evaluate the physical structure and optoelectronic characteristics of Ta_2O_5 waveguides with CIS (Conductor-Insulators-Semiconductor) nonvolatile memory structure.

Tantalum pentoxide (Ta_2O_5) thin films have been made on a silicon substrate by a similar method in the previous papers[2],[3] such that a Ta film is deposited on a thermally oxidized silicon wafer by sputtering in an argon atmosphere and then the deposited Ta film is oxidized to Ta_2O_5 film at 550°C in O_2 gas flows. The oxidation time of Ta_2O_5 is determined in order to obtain better CIS memory characteristics and found to be about 60 minutes longer than the time necessary to get the transparent Ta_2O_5 film.

Fig.1 shows the optical waveguide modes of a Ta_2O_5 thin film on the oxidized silicon wafer, where the refractive indices of a Ta_2O_5 film and a SiO_2 are 2.15 and 1.46 respectively. Fig.2 shows the propagation of light from a He-Ne laser (λ = 6328 Å) in a Ta_2O_5 film on a thermally oxidized silicon substrate. Transmission losses have been measured by using rutile prism couplers in TM_1 mode. The attenuation of the Ta_2O_5 film (~5000Å) due to the scattering loss is considered about 5.6dB/cm from curve 1, because the leakage of the guided light to a Si substrate is theoretically negligible in the case of curve 1 (thickness of SiO_2 : 7410Å). Curve 2 (thickness of SiO_2 : 2920Å) shows 6.7dB/cm in loss. The attenuation of curve 2 is caused by the scattering loss and the leakage loss. The leakage loss 1.1dB/cm is found to be accordance with a theoretical estimation considering coupling to Si substrate.

A transparent gate ($In_2O_3 \cdot SnO_2$) is evaporated on Ta_2O_5 film to make CIS memory diode. The photomemory characteristics[4] of the CIS diode is measured by illuminating nonfilteredlights of 1kW Xe lamp as shown in Fig.4. In Fig.4, parallel shifts of V_{FB} are observed according to the applied gate voltage stress.

Fig.5 and Fig.6 show the same photomemory characteristics by the guided He-Ne laser beam. The schematic measurement setup is shown in Fig.3. The enlarged photograph of the guided light passing under the transparent gates (~ 800Å $In_2O_3 \cdot SnO_2$) is shown in Fig.7. It is possible to write the memory and to erase the stored memory charge by the guided light as shown in Fig.5 and Fig.6.

CIS integrated transistor structures which is capable of writing and erasing the stored memory charges by the guided light passing under the gates are fabricated as shown in Fig.8. It is possible to detect the guided light by a PN junction in Si substrate in the device structure of Fig.8.

The technical problems to be solved for further improvements of the device characteristics are selection and design of transparent conductive gate electrode materials. About 800 Å thin $In_2O_3 \cdot SnO_2$ film of the present device gives rise to 10～100 kΩ/□ sheet resistance, which makes this device difficult to operate in more than 1 MHz gate signal. In case of using a thicker $In_2O_3 \cdot SnO_2$ film than 800 Å, the guided light is found to be attenuated mainly under the gate portion. One means of settling this difficulty is considered to fabricate the gate electrode which has tapered ends.

Another desired physical structure of the gate portion is a local reduction of thickness of SiO_2 under the gate without attenuation of the guided light, which makes this device possible to work in a smaller gate voltage. The authors thanks H.Azuma and M.Suzuki for their cooperation for experiments.

References : 1) P.K.Tien and R.Ulrich ; J.Opt.Soc. Am, 60,10,1325(1970). 2) D.H.Hensler et al ; Appl.Opt. 10,5,1037 (1971). 3) M.Fujimori et al ; Topical Meeting on Integrated Optics, TuA2,Feb. (1972). 4) Y.Tarui et al ; Proc 4th CSSD, 145 (1972)

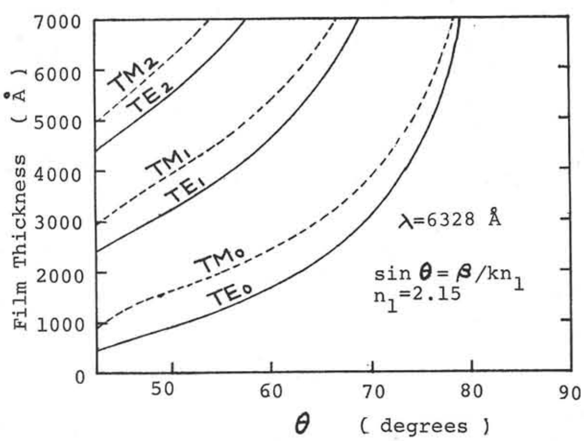


Fig.1 W vs θ for a Ta_2O_5 thin film

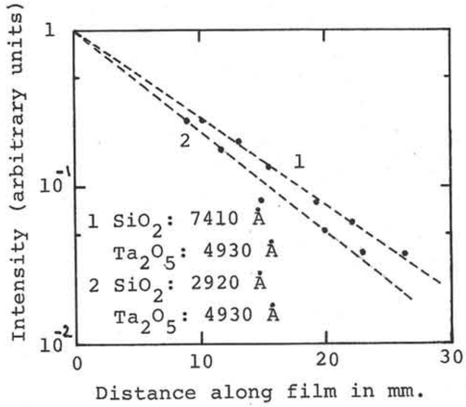
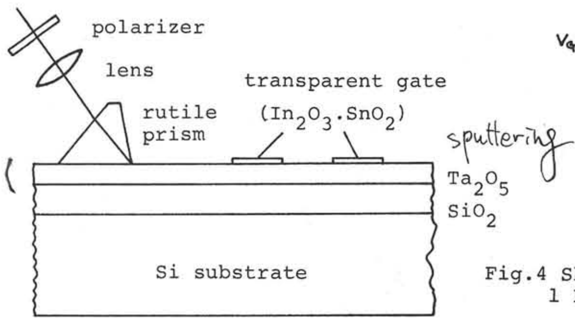


Fig.2 Loss in a Ta_2O_5 film at 6328 Å light wavelength

guide (



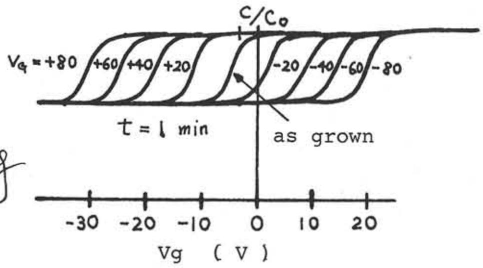
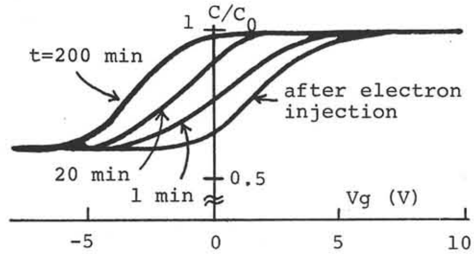


Fig.4 Shifts of C-V curve by illuminating 1 KW Xe lamp under applying bias stress

Fig.3 Schematic figure of measurement setup



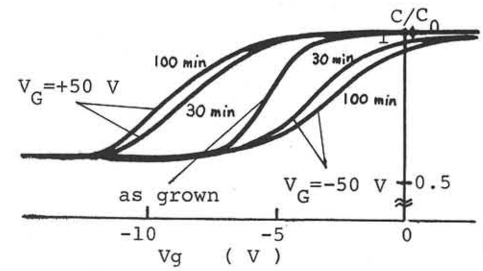
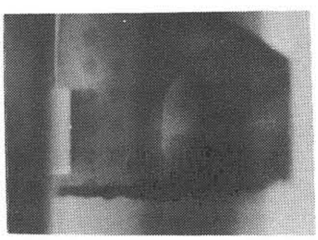


Fig.6 Shifts of C-V curve by waveguide light under no bias stress (Ta_2O_5:3000Å,SiO_2: 3100Å)

Fig.5 Shifts of C-V curve by waveguide light under applying bias stress (Ta_2O_5:3000Å,SiO_2:3100Å)



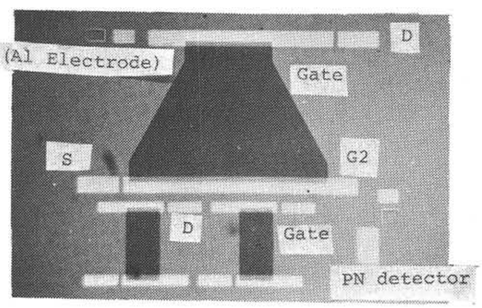


Fig.7 Photograph of propagation light in a Ta_2O_5 film under transparent gate

Fig.8 Photograph of fabricated optical integrated circuit