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Ta_2O_5 optical waveguide on silica substrate fabricated by CF_4 reactive ion etching

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Abstract

We report a high refractive index contrast (～2.1) and ultra-low propagation loss tantalum pentoxide (Ta_2O_5) waveguide. We fabricated the lateral multi-mode Ta_2O_5 waveguides, which has a cross-section of 10μm X 400nm by a CF_4 reactive ion etching. Optimizations of fabrication steps make it achieve to obtain the Ta_2O_5 thin film waveguides with a propagation loss of less than 1 dB/cm at 830nm, which is significant for optoelectronic integrated circuits (OEICs) at 0.8μm wavelength range.

1. Introduction

Recently, the operating speed of large-scale integrated (LSI) circuits is approaching a limit because a global electrical inter-connection is becoming bottleneck. An optical inter-connection instead of traditional electrical interconnection on LSI is proposed to solve this problem [1], [2].

Especially, a crystalline silicon (c-Si) optical waveguide have been studied intensively for the optical interconnection at the 1.55 μm wavelength range. The active device at this wavelength needs to introduce a compound semiconductor such as GaInAs and AlInAs on the c-Si substrate. These materials were difficult to grow epitaxially on Si substrate because of the lattice mismatch between the compound semiconductor and the Si. A wafer bonding technique as one of the approaches to integrate the compound semiconductor layer on Si substrate was reported [3], [4].

On the other hand, the c-Si can be used as the active device such as a photodetector at 0.8 μm-wavelength range. We have fabricated a c-Si avalanche photodiode by 0.18 μm a CMOS standard process [5] and realized a bandwidth of 7 GHz [6].

Ta_2O_5 is a promising candidate material for functional photonic devices, and it is a good host material for rare-earth ions to achieve optical gain [7]. Ta_2O_5 has a high refractive index (～2.2) and a high resistivity [8],[9]. Therefore, this material is suitable for application to realizing dense and compact photonics circuits. Ta_2O_5 thin film slab waveguide were found with no significant absorption peaks over wide wavelengths (600-1700 nm) [10].

In this paper, we report fabrication of Ta_2O_5 optical waveguide on silica substrate by CF_4 reactive ion etching and measurement of propagation losses at 0.8 μm wavelength.

2. Fabrication process

A. Thin Film Deposition

We deposited the Ta_2O_5 thin film with a thickness of 400nm on a silica substrate using spin coating method and infrared ramp annealing. The substrate was cleaned using an ultrasonic cleaning in acetone, ethanol and deionized water for 5 minutes each. The thickness of 400nm was needed as the single-mode propagation. The coating thickness of 110 nm and 70 nm were obtained at the first and the second spin coating process, respectively. The spin coating of 5 times was repeated for reaching 400nm-thick layer. The wafer was baked by infrared lamp annealer at 500 ^{o}C for 30 minutes in air.

B. Channel Waveguide Fabrication

We formed the waveguide with width of 10μm by a photolithography method. We used an S1830 as a photoresist material with a thickness of 2 μm by spin coating, which also used as a protective film at the dry etching. The waveguide height of 400 nm was formed by CF_4 reactive ion dry etching process. The etching rate of 4 nm/min of Ta_2O_5 was achieved with a RF power of 30 W, a gas flow rate of 10sccm and a vacuum pressure of 10Pa. Photoresist were removed by the above substrate cleaning process.

The waveguides were formed using the dicing saw equipment (DAD322 by DISCO Corporation) with various waveguide lengths. The cross sectional view of the

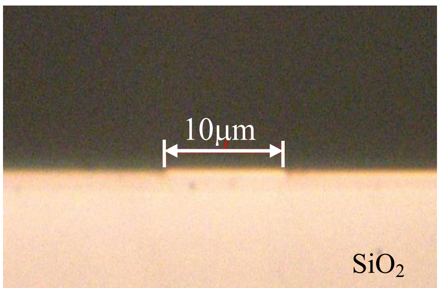

Fig. 1 Cross-sectional view of Ta_2O_5 thin film waveguide.

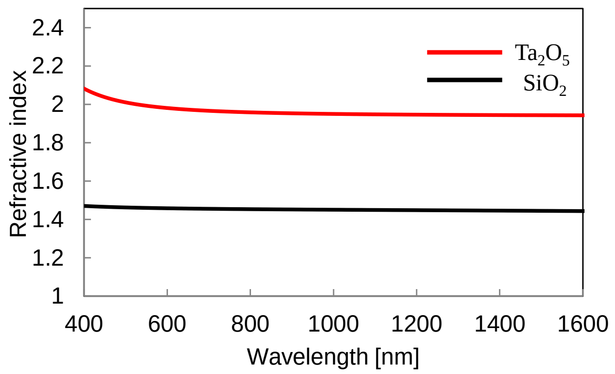

Fig. 2 Wavelength dependence of refractive index of Ta_2O_5 thin film with 400 nm-thick.

waveguide facet was shown in Fig. 1. The waveguide width of 10 µm is observed.

3. Results and Discussion

The Ta_2O_5 thin film thickness and refraction index were measured using a spectroscopic ellipsometry in the wavelength range from 400 to 1600 nm. The wavelength dependence of the refractive indices of Ta_2O_5 and SiO_2 are shown in Fig. 2. The refractive index of around 2 was obtained with Ta_2O_5. This value is higher than the refractive index of SiO_2. Therefore, Ta_2O_5 layer can be used as a core layer.

Optical waveguide loss measurements of Ta_2O_5 optical waveguides were measured by the cutback method at the wavelength of 660, 830, 1310 and 1550nm. Single mode fiber and multi-mode fiber were used for the incident and the output optical coupling, respectively.

The experiment results of losses of Ta_2O_5 optical waveguides at 660nm and 830nm were show in Fig. 3. A coupling loss about 26 dB per facet was observed and the calculated propagation losses with various wavelengths were shown in table 1. The propagation loss of less than 1 dB/cm was observed at 660 nm and 830nm.

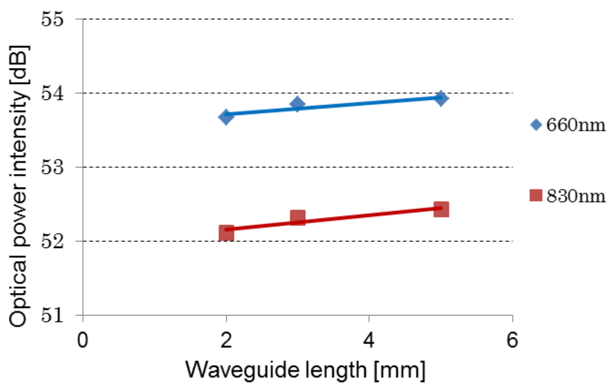

Fig. 3 Loss measurements of Ta_2O_5 optical waveguide by cutback method.

Table 1 Propagation loss of Ta_2O_5 waveguide

Wavelength [nm]	Propagation loss [dB/cm]
660	0.78
830	0.97
1310	1.77
1550	1.81

In the case of Ta_2O_5 waveguide, because of high refractive index differences between the surfaces of core layer and cladding layers (air or silica), a lower propagation loss may be achieved owing to improvement of surface roughness.

4. Conclusions

The Ta_2O_5 optical waveguide was fabricate by the photolithography and CF_4 reactive ion etching. The propagation loss of optical waveguide of around 1 dB/cm was obtained at 830 nm and 660 nm. The waveguide can be expected to use as the waveguide for OE-ICs.

References

[1] J. Davis and J. Meindl, Eds.,*Interconnect Technology and Design for Gigascale Integration*. Kluwer Academic Publishers (2003).
[2] D. A. B. Miller, *Proc. IEEE*, **97** (2009) 1166.
[3] A. W. Fang *et al.*, *Opt. Exp.*, **14** (2006) 9203.
[4] J. V. Campenhout *et al., Opt. Exp.*, **15** (2007) 6744.
[5] K. Iiyama *et al.*, *IEEE Photon. Technol. Lett.,* **22** (2010) 932.
[6] T. Shimotori *et al. OECC2013* (2013) MM1-3.
[7] B. Unal *et al.*, *IEEE J. Quanum Electron.*, **41** (2005) 1565.
[8] R. F. Cava, and J. J. Krajewski, *Appl. Phys. Lett.* **83** (1998) 1613.
[9] J. Lin *et al.*, *Appl. Phys. Lett.* **74** (1999) 2370.
[10] B. S. Ahluwalia *et al.*, *IEEE Photon. Technol. Lett.*, **21** (2009) 1408.