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1 × 3 Silicon Oxynitride Tunable Optical Waveguide Attenuators Based on the Multimode Interference (MMI) Effect

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INTRODUCTION

The power levels of long-haul optical communication systems usually are manipulated by variable optical attenuators (VOAs). These devices usually come with several different configurations. However, when issues involving the costs, large-scale integrations and mass production are of great concerns, then the integrated waveguide-based VOAs certainly become the best candidates to consider. To date, several waveguide-based VOAs have been reported; these include the traditional Mach-Zehnder interferometer (MZI) structure [1], reflective leaky waveguide [2], radiative waveguide bend [3], and multimode interference (MMI) based waveguide [4]. In particular, the MMI effect based on the self-imaging principle [5] has been widely studied and applied to fabricate varieties of devices including the modulators and switches. The primary advantages associated with MMI devices are large optical bandwidth, polarization insensitivity, lower power consumption, relaxed fabrication tolerances, reduced processing costs, and large-scale device integrations.

In this work, we describe the fabrication and testing of center-fed, SiO_2/SiON/SiO_2 1-to-3 tunable MMI optical waveguide attenuators. Silicon oxynitride (SiO_xN_y) is chosen as a waveguide material simply because of its large refractive index range, from 1.45 for silicon dioxide (SiO_2) to 2.0 for silicon nitride (Si_3N_4). The flexibility in tailoring the refractive index of SiO_xN_y core layer by varying the oxygen-to-nitrogen ratio (x/y) during the deposition process using the plasma-enhanced chemical vapor deposition (PECVD) facilitates the optimization of the design of MMI-based waveguide attenuators with greater efficiency.

EXPERIMENTS

The principle behind the operation of 1 × 3 MMI waveguide is based on the symmetric interference [5]. Both center-fed input and MMI multimode waveguides were fabricated using the SiO_2/SiON/SiO_2 symmetrical waveguide structure. All of the layers were deposited in sequence on the silicon substrate via PECVD. Initially, 3μm-thick SiO_2 and 1.5μm-thick SiON layers were deposited first on silicon. Next, input/output and multimode waveguides were lithographically patterned and dry etched down to the SiO_2 bottom cladding layer. The etched waveguides were then capped by a 2μm-thick SiO_2 upper cladding layer. Finally, 50nm-thick Cr and 200nm-thick Ni were deposited and patterned on top of the integrated device as the heating electrode. Figure 1 shows the schematic layout of 1 × 3 MMI tunable optical waveguide attenuator. The refractive index contrast Δn of ~0.0372 between SiO_xN_y core and SiO_2 cladding regions were chosen (n_{SiON} ≈ 1.5082 and n_{SiO2} ≈ 1.4710) by carefully controlling the oxygen-to-nitrogen ratio of SiO_xN_y during the PECVD deposition. In order to tune the

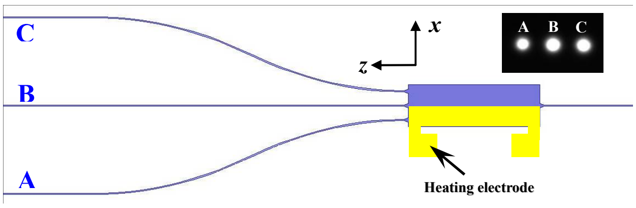

FIG. 1. The schematic layout of 1 × 3 MMI tunable optical waveguide attenuator. All three output channels are labeled as A, B, and C for reference. The inset also shows the corresponding CCD near-field output image for this device before tuning.

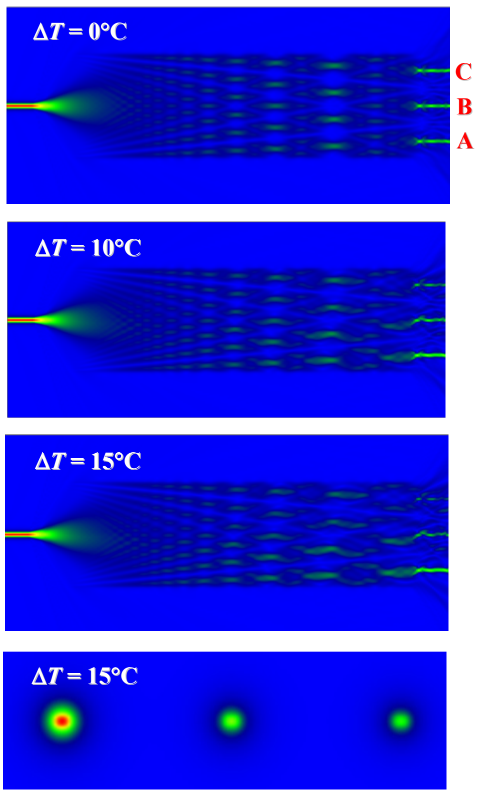

FIG. 2. The BPM simulation of 1 × 3 MMI optical waveguide attenuator under the influence of different applying temperatures as result of the biasing voltage. The simulated cross-sectional beam profile for the device biased with the condition of ΔT = 15°C is also shown.

optical beam intensity of each output waveguide, the refractive index difference between the core and cladding layers must be varied in a gradual fashion. Here, we propose to employ the thermo-optic (TO) effect of SiON with a positive TO coefficient (~10^{-5}/°C) by supplying the driving power to the Cr/Ni heating electrode deposited over the lower half of the MMI multimode section, as shown in Figure 1.

The physical dimensions of the 1 × 3 tunable waveguide attenuators were designed and conformed to the MMI self-imaging principle elaborated earlier by Soldano and Pennings [5]. The beam propagation method (BPM) was employed to optimize the design of 1 × 3 tunable optical waveguide attenuators in order to extract the proper geometrical dimensions of the devices. According to the simulation result shown in Figure 2, the widths of input and output access waveguides were all 3μm. The width and length of the MMI multimode waveguide section were 96μm and 2973μm, respectively. Furthermore, as depicted in Figure 2, the simulation also indicates that as ΔT increases because of TO effect, the optical intensities of three output waveguides initially equaled in magnitude become attenuated in channels B and C but enhanced in channel A. The simulation also agrees with experimental finding shown in Figure 3.

RESULTS AND DISCUSSION

The operation of the tunable MMI waveguide attenuators was first demonstrated by employing 1.55μm continuous-wave (cw) InGaAsP-based laser diode as a light source, a germanium (Ge) photodiode as a output power detector, and a charge-coupled device (CCD) camera as a tool for observing the near-field output beam profile. The laser beam was coupled into the attenuator in

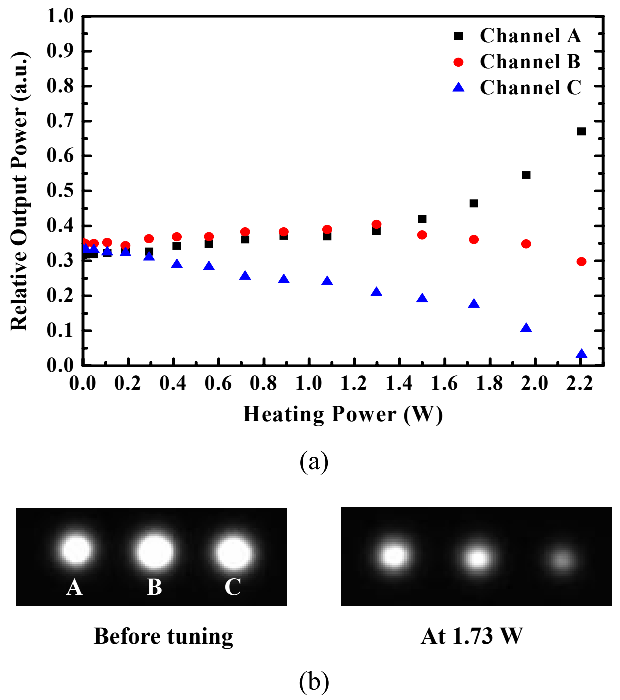

FIG. 3. (a) The relative optical power of three output channels versus the heating power for 1 × 3 MMI tunable optical waveguide attenuator. (b) The corresponding CCD near-field images taken before and after the tuning at the heating power of ~1.73 W.

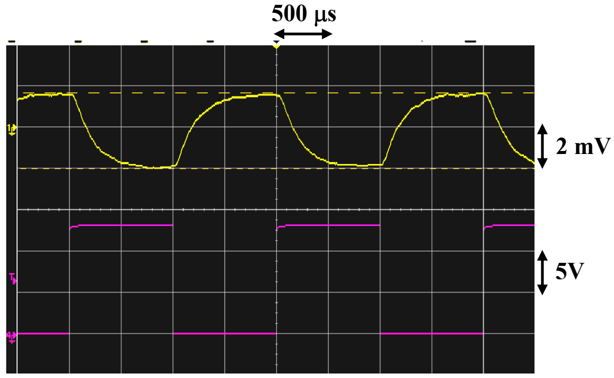

FIG. 4. Optical response (upper trace) of 1 × 3 MMI tunable optical waveguide attenuator biased with an electronic voltage pulse (lower trace) carrying the heating power of ~1.73 W.

normal direction, and both input and output ends of the attenuator were polished in order to increase the coupling efficiency. According to Figure 3, the variations in the output intensities of the three output channels were experimentally observed as the heating power was gradually increased, which was again in good agreement with the BPM simulation shown in Figure 2. Finally, as depicted in Figure 4, with ~1.73 W of heating power applied, the rise and fall times of 1 × 3 MMI tunable attenuator were obtained as 455 and 420 μs, respectively.

CONCLUSIONS

In summary, we have successfully demonstrated SiO_2/SiON/SiO_2 1 × 3 tunable MMI optical waveguide attenuators for the operating wavelength of 1.55μm. With the heating power of ~1.73 W applied, the rise time of 455 μs and fall time of 420 μs for the foregoing devices were determined. Details with regard to the devices simulation, fabrication process, and their characterizations will be reported during the upcoming SSDM 2008 conference.

REFERENCES

[1] D. Li, Y. Zhang, L. Liu, and L. Xu, "Low consumption power variable optical attenuator with sol-gel derived organic/inorganic hybrid materials," *Optics Express*, vol. 14, no. 13, pp. 6029-6034, June 26, 2006.

[2] Y. O. Noh, M.-S. Yang, Y. H. Won, and W.-Y. Hwang, "PLC-type variable optical attenuator operated at low electrical power," *Electron. Lett.*, vol. 36, no. 24, pp. 2031–2032, 2000.

[3] S. M. Garner and S. Caracci, "Variable optical attenuator for largescale integration," *IEEE Photon. Technol. Lett.*, vol. 14, no. 11, pp. 1560–1562, Nov. 2002.

[4] X. Jiang, X. Li, H. Zhou, J. Yang, M. Wang, Y. Wu, and Shigeta Ishikawa, "Compact variable optical attenuator based on multimode interference coupler," vol. 17, no. 11, pp. 2361-2363, Nov. 2005.

[5] L. B. Soldano and E. C. M. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications," *IEEE J. Lightwave Technol.*, vol. 13, no. 4, pp. 615-627, 1995.