

# Influence of thermal isolating grooves on the performance of the Mach-Zehnder interferometer-type thermo-optic variable optical attenuator

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**Abstract.** Two types of silicon-on-insulator thermo-optic variable optical attenuators (VOAs) based on a Mach-Zehnder interferometer and a multimode-interference coupler are fabricated, one with thermal isolating grooves to improve heating efficiency and the other without. Comparison of optical and electrical properties, such as insertion losses, the maximum attenuation levels and the corresponding power consumptions, and the response times, is carried out between the two types of VOAs. The comparison results indicate that use of thermal isolating grooves leads to better values for most characteristics and is an effective way to improve the performance of Mach-Zehnder interferometer-type thermo-optic devices. © 2005 Society of Photo-Optical Instrumentation Engineers.  
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Subject terms: variable optical attenuator; thermal isolating grooves; Mach-Zehnder interferometers; insertion loss; power consumption; response time.

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## 1 Introduction

Variable optical attenuators (VOAs) play an important role in modern optical fiber communication systems. Planar-lightwave-circuit (PLC)-type VOAs are superior to mechanical VOAs for their low cost, fast response, thermal stability, and their potential to integrate with other photo-electronic components, especially when combined with silicon-on-insulator (SOI) technology.<sup>1</sup> The thermo-optic effect of silicon utilized to fabricate VOA on SOI wafer was shown in our previous work.<sup>2,3</sup> The maximum attenu-

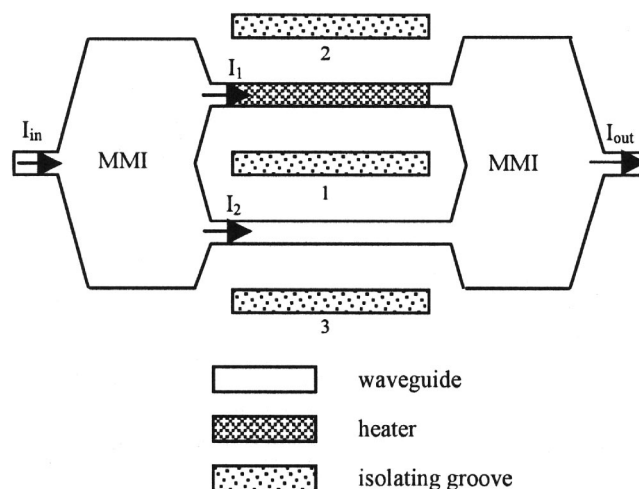


Fig. 1 Top view of VOA with thermal isolating grooves.

ation of 26.3 dB is achieved but the corresponding power consumption is more than 360 mW. In this letter, two types of SOI PLC-type thermo-optic VOAs are fabricated on the same SOI wafer, one with thermal isolating grooves and the other without. Optical and electrical properties are compared.

The basic structure of the VOA is the same as shown in our previous work.<sup>2,3</sup> A Mach-Zehnder interferometer (MZI) and multimode-interference (MMI) coupler are combined to modulate light intensity. When electric voltage is applied to the heater, the phase difference between the two arms transfers to a light intensity modulation on the MMI combiner output port. In order to obtain a high attenuation level, a symmetrical structure is required for the two arms of the MZI, with the exception of modulating heater.

The power consumption of the VOA in our previous work is more than 360 mW at the attenuation of 26.3 dB. We believe that a great amount of power is consumed by the heat diffusion to the other arms because of the high thermo-optic coefficient of silicon, resulting in a decrease in the phase difference between the two arms. The response time is also affected for the same reason. To improve the modulating efficiency, the path of heat diffusion between the two arms must be cut off.<sup>4</sup> Figure 1 shows the top view of the proposed thermo-optic VOA with thermal isolating grooves. Three grooves are introduced on the modified VOA. Groove 1 is etched to isolate the heat transfer between the two arms, and groove 2 is etched to prevent

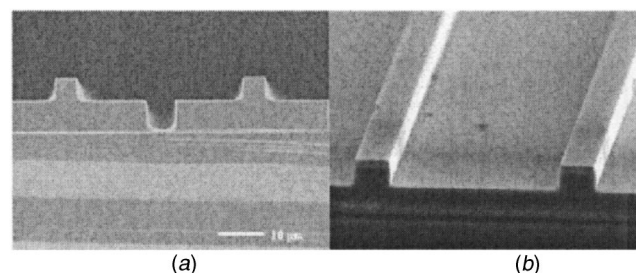
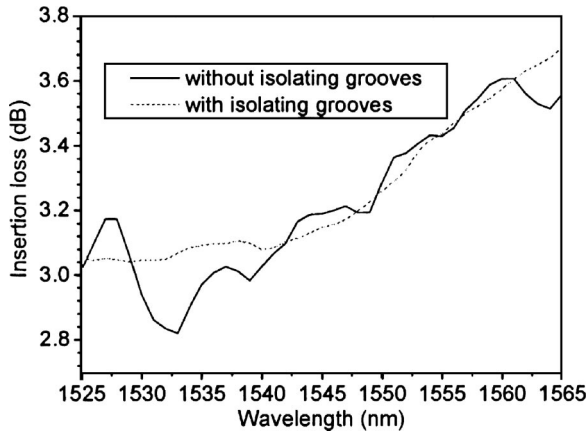


Fig. 2 SEM picture of the modulation region of VOAs with (a) and without (b) isolating grooves.



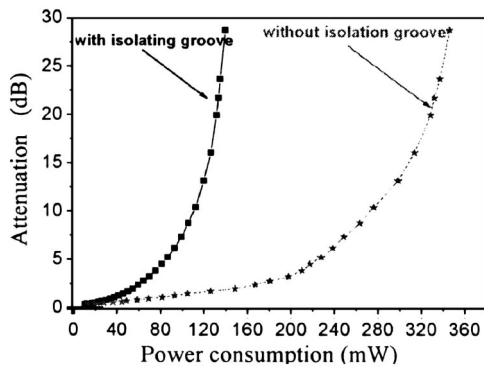
**Fig. 3** Wavelength-dependence of insertion losses of the two types of VOAs.

lateral heat diffusion. Groove 3 is introduced to keep the device symmetric to obtain high attenuation levels.

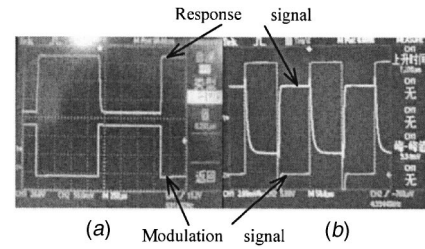
An 11- $\mu\text{m}$ -thick SOI wafer on (100) substrates with a 1- $\mu\text{m}$ -thick buried  $\text{SiO}_2$  layer is etched 4  $\mu\text{m}$  to form a rib waveguide by inductive coupled plasma (ICP) etching. Then a 0.1- $\mu\text{m}$ -thick  $\text{SiO}_2$  cladding is grown thermally. After that, 0.1- $\mu\text{m}$ -thick metal Ti is deposited on the modulating arm as the heater. Last, three 6- $\mu\text{m}$ -wide grooves are etched onto the buried silica for the VOA with isolating grooves. Figure 2 shows the SEM picture of the modulation region of the two types of VOAs.

Comparison of the insertion losses of the two types of VOAs is shown in Fig. 3. The fiber-device-fiber insertion loss of VOA without isolating grooves at the wavelength range of 1525 to 1565 nm is 2.8 to 3.6 dB, versus 3.0 to 3.7 dB for the one with isolating grooves. The change of insertion loss is not obvious.

The relationship between the power consumption and the attenuation level of the two types of devices is measured by changing the heating power as shown in Fig. 4. The existence of thermal isolating grooves does not affect



**Fig. 4** Comparison of attenuation against power consumption for VOAs with and without thermal isolating grooves.



**Fig. 5** Dynamic response of VOAs with (a) and without (b) isolating grooves.

the attenuation range but decreases the power consumption of VOA greatly. For the device with and without isolating grooves, the power consumptions at the attenuation of 29 dB are 140 and 346 mW, respectively. Introducing isolating grooves is an effective method to prevent heat waste and reduce power consumption.

The response time is measured by applying a square electric signal to the heater and detecting the output power simultaneously using a p-i-n photodetector. As shown in Fig. 5, for a VOA without isolating grooves, the rise time is 7  $\mu\text{s}$  and the fall time is 97  $\mu\text{s}$ . In the case of the one with isolating grooves, the rise time is 8  $\mu\text{s}$  and the fall time is 32  $\mu\text{s}$ . Note that the output power decreases with the increase in heating voltage and vice versa. With isolating grooves, the heating efficiency is improved when electric voltage is applied on the heater, decreasing the fall time greatly. On the other hand, the isolating grooves slow down the cooling course by isolating the heat diffusion to the remote area, increasing the rising time. The total response time was reduced from 104 to 40  $\mu\text{s}$ .

In conclusion, electrical and optical properties of a thermo-optic variable optical attenuator fabricated on a SOI wafer with and without thermal isolating grooves are compared. The introduction of isolating grooves makes the power consumption of the VOA decrease from 346 to 140 mW at the attenuation of 29 dB, and the response frequency increases from about 10 to 25 kHz, while not affecting the insertion loss and attenuation level.

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