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A 1×2 Power-Monitoring Splitter Based on a Ge/Si Hybrid MMI Structure

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Abstract

A 1×2 optical power splitter with power monitoring capability based on a Ge/Si hybrid structure is proposed and demonstrated. An optical power splitter based on multimode interference (MMI) is designed for silicon and a short piece of germanium (Ge) layer is then placed above the MMI structure, where the electric field is weak. Therefore, only a small portion of the input optical power is absorbed by the Ge layer for power monitoring, while transmission and splitting of light in the Si waveguide remain minimally affected. Fabricated using standard CMOS processes, the device exhibits an insertion loss of ~ 0.5 dB and a responsivity of ~ 9 mA/W at -1 V around 1550 nm. Without altering the fundamental MMI-based splitter, this design simultaneously achieves both optical splitting and power monitoring.

1. Introduction

Silicon photonics has emerged as the primary choice for large-scale integrated photonic networks, benefiting from the well-established capability of Ge epitaxial heterogeneous integration and its compatibility with CMOS processes. Due to the advantages of low loss, high integration density, and mass production, silicon photonics offers a compelling solution for applications in diverse fields, including optical communications, optical computing, microwave photonics, LiDAR, etc.

In large-scale networks, power monitoring in critical nodes is often important, to determine whether the system, or certain parts of the system is working correctly. Furthermore, for reconfigurable systems/blocks where precise tuning is in need, through either thermo-optics or electro-optics effect, the inline power probing is especially crucial. In most cases of reconfigurable blocks, a Mach-Zehnder interferometer (MZI) based on two power splitters is implemented as the fundamental architecture [1-3].

The conventional way for probing power on-chip is to use a directional coupler followed by a nearby Ge/Si photodetector (PD) to extract a small portion of light for monitoring [1]. However, the additional components enlarge the footprint and increase the complexity of integrated photonic circuits, limiting scalability. Alternative approaches leveraging silicon's nonlinear effects for all-optical detection have been proposed [4,5]. Nevertheless, these effects are either extremely weak, or requires specialized process, leaving such methods constrained by limited integration capabilities or intricate fabrication requirements.

Here a 1×2 power-monitoring optical splitter based on a Ge/Si hybrid multimode interference (MMI) structure is proposed and experimentally demonstrated. The Ge layer efficiently absorbs the low-intensity optical power from the electric field, converting it into a measurable photocurrent, while introducing negligible impact on the transmission and splitting performance of the silicon waveguide. This integrated configuration enables power monitoring of the operational status in MZI units without requiring additional components or complex back-end circuits. Since power splitters are widely employed in optical networks, the capability of power monitoring could be enabled with slight modification as this work proposed, which would be essential for next-generation reconfigurable photonic networks on chip.

2. Design and Simulations

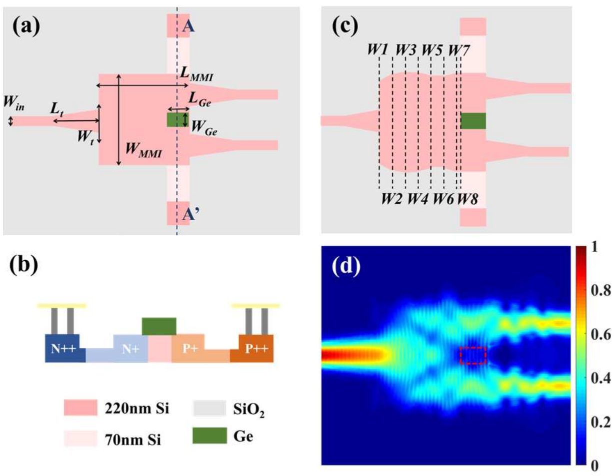

Figure 1. (a) Schematic of a proposed 1×2 power-monitoring splitter with Ge/Si hybrid structure; (b) cross section of the power detection region along A-A' in (a); (c) schematic of the PSO-optimized structure; (d) simulation result of the electric field distribution at 1550 nm for (c).

The schematic of a proposed 1×2 power-monitoring splitter based on a conventional symmetrical MMI structure is illustrated in Fig. 1 (a). The two output waveguides are placed near the two-fold image position of the MMI for low-loss and balanced power splitting. And the central area between the two strong spots exhibits a weak electric field distribution. Then by placing a piece of Ge layer atop of this weak field distribution region, the optical power could be monitored with little influence to the transmission and splitting. To facilitate interconnections with other components in the integrated photonic circuit, the input and output ports of the splitter are standard fully-etched single-mode waveguides with a width (W_{in}) of 0.45 μm. Tapers are used to connect the input/output waveguides to the MMI section with lower transmission loss. The width of the taper gradually increases from 0.45 μm to 1 μm (W_t) over a length of 5 μm (L_t) for a stable mode transmission. As shown in Fig.1 (a), a Ge layer is placed on top of the central MMI termination for monitoring. Notably, the size of the Ge layer is constrained by design rules of the foundry, where a minimum width of 0.5 μm (W_{Ge}) and a minimum length of 2 μm (L_{Ge}) are required. To obtain a weak electric field region large enough to accommodate the minimum size of Ge segment, the width of the MMI is set as 3 μm (W_{MMI}) and the length is set around 7.2 μm (L_{MMI}). Fig. 1(b) illustrates the cross-section of the Ge/Si hybrid region, which is similar to a short conventional lateral PIN Ge/Si photodetector. To effectively transport and collect the generated carriers from Ge, the waveguide beneath the Ge layer is doped with varying carrier concentrations and features a deeply-etched rib waveguide (etch depth of 150 nm).

To further improve the transmission of the power-monitoring optical splitter, the shape of the device is optimized using particle swarm optimization (PSO) algorithm. As shown in Fig.1 (c), the MMI body of the device is segmented into a number of isosceles trapezoidal elements, where the widths are optimized using the PSO algorithm. Due to the MPW regulations that angles should be larger than 85°, additional constrains are applied. Fig. 1(d) plots the simulated electric field distribution for the PSO optimized Ge/Si hybrid power-monitoring optical splitter at 1550 nm. The position of the Ge layer is highlighted by the red dashed box. And the insertion loss is simulated to be less than 0.57 dB for C-band.

3. Experiment Results

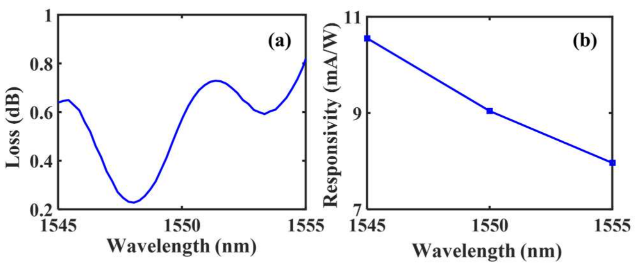

Figure 2. Experimental results of the Ge/Si hybrid power-monitoring optical splitter: (a) loss; (b) responsivity.

The optimized 1×2 Ge/Si hybrid power-monitoring optical splitter is fabricated with a standard MPW silicon photonic processes (CUMEC, China). The dark current of the Ge/Si power monitoring optical splitter is measured to be 1.7 nA at -1V. As shown in Fig. 2 (a), the transmission loss of the power monitoring optical splitter is less than 0.8dB from 1545 nm to 1555 nm. The minimum transmission loss of is 0.20 dB loss at 1548 nm. A responsivity of ~ 9 mA/W at -1V is measured around 1550 nm, as is seen in Fig.2 (b).

4. Conclusion

In summary, a 1×2 power-monitoring splitter based on a Ge/Si hybrid MMI structure has been experimentally demonstrated. By placing a small piece of Ge layer atop of the weak field distribution region of the splitter, efficient power monitoring could be enabled simultaneously. A responsivity of 9 mA/W at -1V around 1550 nm and a minimum insertion loss of ~ 0.2 dB at 1548 nm is measured for the PSO optimized power-monitoring splitter, featuring a compact footprint of ~ 8.6×10 μm. As 1×2 power splitters are widely employed in large scale integrated optical networks, the proposed multifunctional device enables the capability of efficient power probing at critical nodes, which would be of importance to applications demanding comprehensive powering monitoring.

Acknowledgements

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