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Vertical SiC taper with a small angle fabricated by slope transfer method

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In this Letter, a slope transfer method to fabricate vertical waveguide couplers is proposed. This method utilises wet etched Si as a mask, and takes advantage of dry etching selectivity between Si and SiC, to successively transfer the profile from the master into SiC. By adopting this method, a <2° slope is achieved. Such a taper can bring the coupling efficiency in SiC waveguides to 80% (around 1 dB loss) or better from around 10% (10 dB loss) without taper. It further increases the alignment tolerance at the same time, which ensures the successful development of a plug-and-play solution for optical sensing. This is the first reported taper made in SiC.

Introduction: Waveguides are now widely used in many areas from optical communication to bio-medical sensing. However, the alignment and coupling between optical sources/ fibres and waveguides are still problematic for practical applications in some fields, especially where the plug-and-play system is needed. Traditionally used materials for optical waveguides include Si, SiO₂, SiN and SiC and waveguides made from these materials are normally sub-micron thick and several-micron wide; thus experiments need to be conducted under a microscope on a precise optical stage, making the fibre to waveguide coupling a challenge. To relieve this handling problem, couplers with wider and thicker tapers need to be added to the waveguides. Horizontal tapers can easily be obtained by pattern design and lithography, while vertical tapers with slopes need some effort. Current methods to fabricate vertical tapers include greyscale lithography [1], thermal reflow [2] and wet etch in a silicon wafer with a tilted (1 1 1) crystal orientation [3]. Greyscale lithography is a binary process and results in a step profile surface, while thermal reflow takes time and has edge bead effects [4, 5]. Both the step profile and the abrupt nature of the induced edge bead will influence the optical transmission and hinder the coupling effectiveness. Furthermore, the thickness of the photoresist mask depends on the thickness of etched material and the etching ratio between them, so thick photoresist will be needed when etching hard materials. A more efficient method is here developed for fabricating vertical taper with several-micron in thickness and made of hard materials. In this Letter, we propose a slope transfer method which takes advantage of the etching rate ratio between silicon and the taper material, to transfer slope from silicon into the taper.

Design and simulations: In the waveguide design, SiC is selected as the core material due to its excellent optical, mechanical, electrical properties and also its chemical resilience. From an optical point of view, it is transparent above 0.5 μm wavelength, enabling wavelengths in the visible and the near infrared range to be guided. It has a rather high refractive index generally ranging from 2.3 to 2.5 [6] or even higher, making it a promising material in optics and more preferable when fabricating bent waveguides. SiC is selected as the core material due to its excellent optical, mechanical, electrical properties and also its chemical resilience. From an optical point of view, it is transparent above 0.5 μm wavelength, enabling wavelengths in the visible and the near infrared range to be guided. It has a rather high refractive index generally ranging from 2.3 to 2.5 [6] or even higher, making it a promising material in optics and more preferable when fabricating bent waveguides. 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the coupler, the transfer process needs to be improved to achieve a surface of better uniformity and with a smaller slope angle.

(2) Slope transfer without bonding layer: To optimise the fabrication, the transfer photoresist layer was removed by directly depositing the masking Si layer on top of the SiC taper layer instead. The fabrication method is still taking advantage of the etching rate difference between Si and SiC for slope transfer. The process is shown in Fig. 3. Firstly, a 5 μm-thick SiC layer was deposited by PECVD under 400°C with a gas mixture of SiH₄ and CH₄ [7]. Then a thick layer of α-Si was sputtered on the SiC layer in Sigma followed by a layer of PECVD SiO₂ acting as a mask layer for wet etching. After all the layers were prepared, an etch window was open in SiO₂ and then the whole wafer was dipped into a 25 wt% TMAH solution at 85°C. A short time over etch was applied to guarantee that the Si mask was etched through to reach the SiC layer underneath. After the wet etch of α-Si in TMAH, a curved slope profile was formed in silicon. Then the wafer was etched by an SF₆/O₂ gas mixture under 10°C in Omega Trikon RIE etcher. Due to the different etching rate between Si and SiC, the profile in silicon was transferred into SiC with a different (slighter) slope under the dry etch of Omega. After finishing the whole process, the slope profile was inspected with a Keyence VK-X 3D scanning confocal laser microscope. The profile is shown in Fig. 6. Then the slope is measured on section A to be lower than 2° (shown in Fig. 7). The coupling efficiency will be greatly improved to around 70% with a taper height of 6 μm, which is efficient enough to meet the requirement of the optical sensing systems. Compared with the former process, this method skipped the bonding step, which decreased the surface roughness caused by burnt effect and non-uniformity of the bonding photoresist as cooling is difficult with the resist. The surface roughness of reactive ion etched SiC in SF₆/O₂ is measured to be lower than 1 nm [10]. The transmission loss in SiC will be way lower than 1 dB/cm according to previous research in [11]. Therefore, the total transmission loss in SiC coupler will be <1 dB. The benefit of the coupler, which decreased 9 dB insertion loss, far weighs the induced transmission loss and demonstrates such a coupler to be efficient.

Conclusion: In this Letter, a slope transfer method was proposed to achieve a small slope in SiC which is used in waveguide taper fabrication. A <2° slope was achieved by this process. This method is demonstrated to greatly reduce the coupling loss and can be well integrated with former designed SiC waveguide, which enables the realisation of a plug-and-play system for optical sensing.

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One or more of the Figures in this Letter are available in colour online.

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References
8 Xin, Y., Pandraud, G., Pakula, L.S., et al.: ‘Combination of LPCVD and PECVD SiC in fabricating evanescent waveguides’. IEEE NEMS, Sendai, Japan, April 2016, pp. 1–4