a-Si:H Layer Enabling a sub-1.2 dB Loss SiN-III/V-SiN Transition for Evanescently Coupled Lasers at 920 nm

K. Akritidis[1], M. Billet[1], S. Saseendran[2], S. Poelman[1], G. Roelkens[1], J. Brouckaert[2] and B. Kuyken[1]

1. Photonics Research Group, Department of Information Technology, Ghent-University-imec, Technologiepark-Zwijnaarde 126, 9052, Ghent

2. IMEC, Kapeldreef 75, 3001 Heverlee, Belgium

Konstantinos.Akritidis@ugent.be

***Abstract*— Overcoming the high index contrast between SiN and III-V amplifiers is essential for the realization of heterogeneously integrated evanescently coupled lasers. Here, we propose a design based on a-Si:H as the transition layer, demonstrating sub-1.2 dB loss for the whole SiN-III/V-SiN transition at 920 nm.**

Keywords—SiN photonics, integrated lasers, evanescent coupling, III/V amplifiers

I. Introduction

Developing integrated lasers that emit in the near-infrared (NIR) band is essential for a variety of applications such as Optical Coherence Tomography (OCT). Silicon nitride (SiN) has proven to be very promising as a material platform for integrated optics due to its large transparency window, ultra-low losses and negligible two-photon absorption [1]. However, its low refractive index impedes the integration of active materials. Although butt coupling can be used [2], adiabatic coupling remains of high interest, as it offers broadband, fabrication tolerant transitions and can demonstrate very high coupling efficiencies [3]. Therefore, one needs to find a material that is index compatible with relatively low losses that can be used as the intermediate step. This will allow the adiabatic transition through the evanescent field from the ultra-low-loss SiN to the heterogeneously integrated (by employing for instance micro-transfer printing [4]) III-V gain section. Even though such devices have been demonstrated in the past at longer wavelengths [5], finding a suitable material with the aforementioned properties at shorter ones still remains a challenge to be addressed. In this work, we propose a taper design based on a hydrogenated amorphous silicon (a-Si:H) recipe with optimized losses for short wavelengths.

II. Design and Measurements

A. Concept

A schematic drawing of the evanescently coupled device is shown in Fig. 1. The GaAs-based semiconductor optical amplifier (SOA) sits on top of the intermediate layer. In order to facilitate the coupling between the structures, the phase

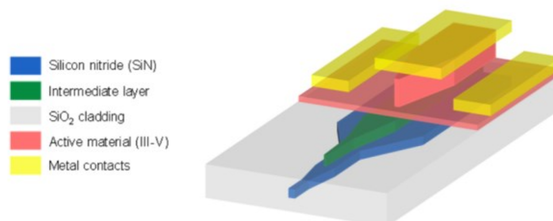


Fig. 1. Drawing schematic of the device. The intermediate layer allows the transition of the mode from SiN to the GaAs-based SOA.

matching condition should be met. This means that the effective index of the TE ground mode of the intermediate layer should be equal to the effective index of the TE ground mode of the GaAs-based SOA [6]. This showcases the importance of the refractive index compatibility of the transition layer, which should not be very far apart from the typical index of the GaAs (≈ 3.4).

Although silicon has a high index, it cannot be utilized due to its absorption at the wavelength of interest. Instead, materials like gallium phosphide (GaP), indium gallium phosphide (InGaP), aluminum gallium arsenide (AlGaAs), and hydrogenated amorphous silicon (a-Si:H) can be used. While the aforementioned III/V candidates are very promising due to their low absorbance, they are difficult to integrate into the current technological processes. On the other hand, a-Si:H, not only has a higher index, but is CMOS compatible, which makes it a very attractive solution.

B. a-Si:H absorption measurements

In order to acquire the refractive index (n) and extinction coefficient (k) of a-Si:H, ellipsometry measurements were made as shown in Fig. 2. The wafer consisted of 200 nm thick a-Si:H on top of 2 um thermal oxide on silicon substrate. The index at 920 nm was found to be 3.61 which is close to the GaAs and therefore can allow the phase matching condition. Regarding the absorption measurements with ellipsometry however, k was found to be zero for wavelengths longer than 788 nm. This does

This work was supported by the European Union's Europe research and innovation programs under agreement 101070622 (CALADAN)

not depict the reality but instead the method's unsuitability for the precise evaluation of the absorption losses.

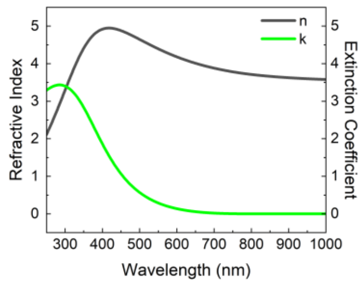
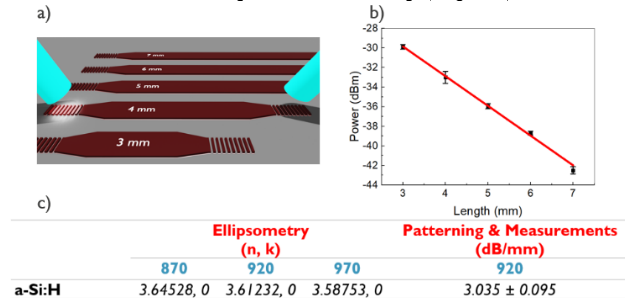


Fig. 2. Ellipsometry measurements (Woollam) done on 200 nm a-Si:H for the acquisition of the (n, k) profile.

To get a clear view of the losses, the wafer was sequentially patterned with electron beam lithography (EBL), and loss measurements were conducted as shown in Fig. 3a by employing the cutback method. In total, five different structures were measured, with the grating couplers designed at 920 nm. Among the structures, only the straight waveguide's length was varying. Three copies for each structure were included in order to evaluate the processing variations. The width of the cores was chosen to be 20 um in order to minimize scattering losses. This way, most of the losses would originate from the material itself. By measuring the power at the output for different lengths, the loss was obtained through a linear fitting (Fig. 3b).



	Ellipsometry (n, k)			Patterning & Measurements (dB/mm)
	870	920	970	920
a-Si:H	3.64528, 0	3.61232, 0	3.58753, 0	3.035 ± 0.095

Fig. 3. (a) A schematic of the test structures for the loss measurements. The results of the measurements are shown in (b). For each length, three copies were measured at 920 nm. To extract the loss value, a linear fitting is done. (c) Complete summary of the measurements.

Fig. 3c shows the summary of the measurements. With an index of 3.61 and with losses equal to 3 ± 0.095 dB/mm, we will proceed with the design of the taper. By optimizing the adiabatic taper geometry, the transition losses can be minimized, as well as the coupling to any TM or higher-order TE modes.

C. Taper design at 920 nm

Two different thicknesses of a-Si:H are used for the transition of the mode. First a 220 nm a-Si:H layer will be deposited in order to allow coupling to the III-V and then a partial etch of 150 nm will take place, leaving 70 nm a-Si:H. The reasoning behind this choice is twofold. First, the taper tip of the III-V waveguide should not be designed too narrow, since it would not correspond to a realistic processing because of the high aspect ratio. Therefore, a thin transition layer cannot work.

Second, the 220 nm thick a-Si:H cannot be phased matched with SiN, as the minimum resolution of the a-Si:H tip that can be obtained through DUV is 130 nm. Therefore, two different thicknesses of a-Si:H are required for the SiN-GaAs transition.

For the simulations, a commercial software was used (Lumerical MODE Solution). The Finite Difference Eigenmode (FDE) solver was employed in order to obtain the modes (Fig. 4) and the bidirectional EigenMode Expansion solver (EME) for the light propagation through the tapers.

Through EME simulations it was found that the total length required for the whole SiN-III/V-SiN transition is 310 um with 95% transmission. This results in less than 1.2 dB transition loss. This order of value is far from prohibitive as integrated SOAs can be fabricated with more than 20 dB optical gain [2].

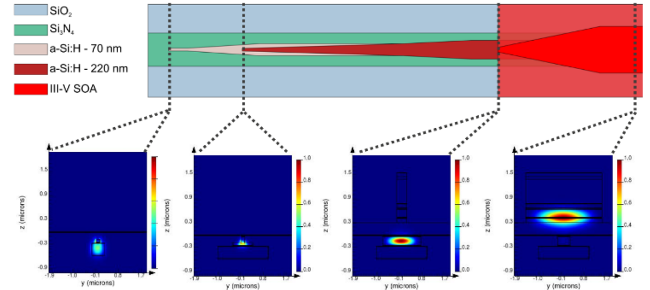


Fig. 4. Taper schematic of the transition from SiN towards GaAs. FDE results are also shown in the most important regions: whenever a new structure is introduced.

III. Conclusion

a-Si:H can be used as a transition layer for integrated evanescently coupled lasers at 920 nm achieving sub-1.2 dB losses. By optimizing the taper design, the losses for the whole transition could be reduced even further. This paves the way for an efficient SiN-III/V-SiN transition in the NIR optical band, leading to the possibility of next heterogeneous lasers-on-a-chip development. Such lasers can find applications in many high impact areas such as medical imaging (OCT).

References

[1] Jack A. Smith, Henry Francis, Gabriele Navickaite, and Michael J. Strain, "SiN foundry platform for high performance visible light integrated photonics," Opt. Mater. Express 13, 458-468 (2023)

[2] Tran, M.A., Zhang, C., Morin, T.J. *et al.* Extending the spectrum of fully integrated photonics to submicrometre wavelengths. *Nature* 610, 54–60 (2022). https://doi.org/10.1038/s41586-022-05119-9

[3] Paramjeet Kaur, Andreas Boes, Guanghui Ren, Thach G. Nguyen, Gunther Roelkens, Arnan Mitchell; Hybrid and heterogeneous photonic integration. *APL Photonics* 1 June 2021; 6 (6): 061102. https://doi.org/10.1063/5.0052700

[4] G. Roelkens *et al.*, "Micro-Transfer Printing for Heterogeneous Si Photonic Integrated Circuits," in *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 29, no. 3: Photon. Elec. Co-Inte. and Adv. Trans. Print., pp. 1-14, May-June 2023, Art no. 8200414, doi: 10.1109/JSTQE.2022.3222686.

[5] Camiel Op de Beeck, Bahawal Haq, Lukas Elsinger, Agnieszka Gocalinska, Emanuele Pelucchi, Brian Corbett, Günther Roelkens, and Bart Kuyken, "Heterogeneous III-V on silicon nitride amplifiers and lasers via microtransfer printing," Optica 7, 386-393 (2020)

[6] Yuting Shi, Bernardette Kunert, Yannick De Koninck, Marianna Pantouvaki, Joris Van Campenhout, and Dries Van Thourhout, "Novel adiabatic coupler for III-V nano-ridge laser grown on a Si photonics platform," Opt. Express 27, 37781-37794 (2019)