Multimode interference reflector for anti-colliding III-V-on-silicon-nitride mode-locked lasers

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Abstract: We present a type of hybrid a-Si:H/SiN broadband reflector using a multimode interference reflector topology. This reflector is developed specifically to realize an anti-colliding pulse mode-locked laser using the III-V-on-silicon-nitride platform. In this platform the layer of hydrogenated amorphous silicon is also used to bridge the index contrast between the silicon nitride and active III-V layer.

1 Introduction

In previous years, integrated semiconductor mode-locked lasers (MLL) have become very promising frequency comb sources for several applications, such as dual-comb spectroscopy [1]. An example of such an integrated mode-locked laser was demonstrated in [2], where a III-V-on-silicon mode-locked laser with a 1 GHz repetition rate was reported. By implementing the saturable absorber (SA) above the output reflector, the MLL was made to operate in an anti-colliding mode, promising among others higher output powers when compared to other topologies such as colliding-pulse implementations and ring topologies [3]. The performance of these devices is however limited by the silicon waveguides, which suffer from nonlinear losses such as two-photon absorption. Silicon nitride offers a solution with many advantages such as ultra-low waveguide losses and lower sensitivity to fabrication errors. For a long time the integration of active devices on a passive silicon nitride platform remained challenging, but recently integration of III-V amplifiers and lasers has been demonstrated [4], [5]. We want to develop a high performance, low repetition rate anti-colliding mode-locked laser on a silicon nitride on insulator platform. A schematic drawing of such an anti-colliding MLL is shown in the top of **Figure 1.** To bridge the index difference between silicon nitride (Si_3N_4) and indium phosphide (InP) based amplifiers ($\Delta n \sim 1.4$), we use an intermediate layer of hydrogenated amorphous silicon (a-Si:H), similar to the approach in [4]. To achieve the high performance promised by the anti-colliding approach, a broadband output reflector close to the SA is necessary. However, broadband and compact reflectors such as broadband Bragg gratings are difficult to realize on the silicon nitride platform. A compact and broadband solution can be found in multimode interference reflectors (MIR), which are based on multi-mode interferometers combined with reflective waveguide facets. Theoretical analysis and measurement results for InP-based MIRs were presented in [6]. Because of the low refractive index contrast of silicon nitride photonic waveguides, MIRs cannot be realized in this platform. In this work, we demonstrate that these MIRs can be realized making use of the intermediate a-Si:H layer of our platform. This offers an excellent candidate as a compact and versatile output coupler for an integrated III-V-on-silicon-nitride anti-colliding mode-locked laser and offers a compact reflector for applications on the SiN platform where gratings and compact broadband reflectors are challenging to realize due to the low refractive index contrast.

2. Design and fabrication

As described in [6], MIRs are designed starting from a regular multimode interferometer (MMI) and etching two 45° degree facets in the MMI, which meet at the exact center of the MMI. This approach exploits the self-imaging properties of these MMIs, to create the desired reflection pattern. Given the need for total internal reflection an MIR cannot be realized in most silicon nitride platforms. For the purpose of our anti-colliding mode-locked laser, we require a 2-port MIR in the a-Si:H layer. Such a 2-port MIR was designed for a reflection/transmission ratio of 50/50. Starting from a chosen width W for the multimode waveguide section, the theoretical length and position of the input ports can easily be found as $L=3L_\pi/12$ and $P_1=W/4$, $P_2=3W/4$ respectively. Starting from these theoretical predictions, these MIRs were simulated and optimized using the Lumerical FDTD and varFDTD solvers. From these the following nominal parameters were obtained: $W=4\mu m$, $L=29\mu m$, $P_1=1\mu m$, $P_2=3\mu m$. The input and output single mode waveguides ($W=0.6\mu m$) are tapered towards the MIR to a width of $1.5\mu m$, to achieve a better transition. The devices are fabricated starting from a silicon nitride wafer, where we deposit the hydrogenated amorphous silicon using plasma-enhanced chemical vapor deposition (PECVD), followed by 2 steps of e-beam lithography and reactive ion etching. In the first step the hydrogenated amorphous silicon is patterned and opened up and the silicon nitride is patterned in the second step. As grating couplers in the amorphous silicon are difficult, we use grating couplers in the silicon nitride and tapers to couple to the a-Si:H. To test the performance of these MIRs, we made a Fabry-Pérot interferometer using two MIRs as

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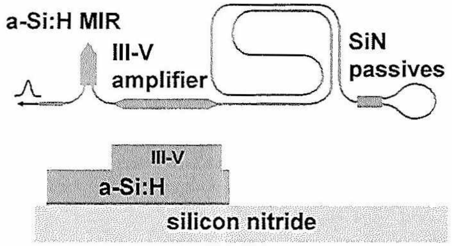
1. Introduction

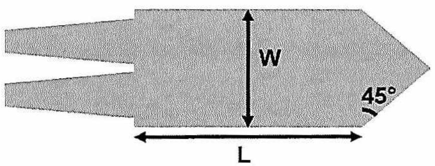
Semiconductor mode-locked lasers (MLL) have become very promising frequency comb sources for several applications, such as dual-comb spectroscopy. Impressive results have been obtained using the III-V-on-Si platform where the saturable absorber was implemented above the output coupler, to obtain an **anti-colliding mode operation**, which promises among others higher output powers. Recently, the **low-loss silicon nitride platform** has gained interest, but lacking options for compact and broadband output reflectors.
Here, we present a type of **hybrid a-Si:H/SiN broadband reflector** using a multimode interference reflector topology. This reflector is developed specifically to realize an anti-colliding pulse mode-locked laser using the **III-V-on-silicon-nitride platform**. In this platform the layer of **hydrogenated amorphous silicon** is also used to bridge the index contrast between the silicon nitride and active III-V layer.

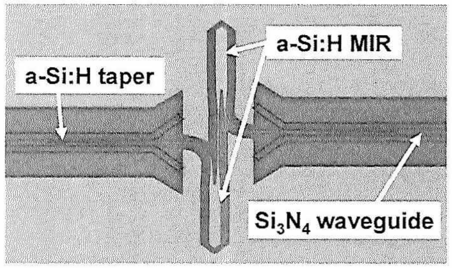
2. Design and Fabrication



Schematic of the envisioned anti-colliding mode-locked laser

A broadband, compact reflector based on multimode interference reflectors



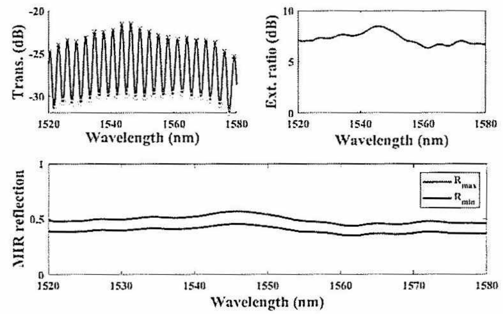


Fabry-Pérot interferometer using two MIRs as cavity mirrors.

3. Experimental Results

- Fabry-Pérot measurements are used to measure the reflection.
- Broadband reflection of about 40% is obtained in a range of > 60nm

MIR length	**28** – 29 – 30µm
MIR width	3.8 – **4.0** – 4.2µm
Port offset	**-0.3µm** – 0µm – 0.3µm
Taper length	**10 µm**



$$R = \frac{1}{G}\frac{\sqrt{D}-1}{\sqrt{D}+1}$$

4. Conclusion

- A **broadband, compact reflector** based on multimode interference reflectors has been created in the **hydrogenated amorphous silicon layer** of our III-V-on-silicon-nitride platform.
- This is a first step that will enable us to make high-performance **anti-colliding mode-locked lasers on silicon nitride**.

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Poster 12 **Monolithic Integrated High-quality Microwave Signal Generation based on External Modulation Technique**

Jessica César Cuello, Alberto Zarzuelo, Robinson C. Guzmán, Luc Augustin, Fernando Martín
Universidad Carlos III of Madrid, SENER Aeroespacial, SMART Photonics

Poster 13 **Multimode interference reflector for anti-colliding III-Von-silicon-nitride mode-locked lasers**

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Poster 14 **Auger recombination in GeSn Quantum Wells**

Aleksey Andreev and E.P. O'Reilly
Tyndall National Institute - University College Cork

Poster 15 **Comparison of "Linear" and "Constant" Inverse Scattering Functions for use in Index-Patterned Fabry-Pérot Lasers**

Niall Boohan and Eoin P. O'Reilly
Tyndall National Institute, Department of Physics, University College Cork

Poster 16 **Thermal investigation of Two-Section Slotted Semiconductor Lasers**

Robert McKenna, Sepideh T. Naimi, Simon Corbett, David McCloskey, and John F. Donegan
School of Physics - Trinity College Dublin, Future Networks and Communications (CONNECT) - Trinity College Dublin, Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) - Trinity College Dublin, Advanced Materials and BioEngineering Centre (AMBER), Trinity College Dublin

Poster 17 **Efficient single-pass second harmonic generation into the far UVC**

E. Z. Ulsig and N. Volet
Dept. of Engineering, Aarhus University

Session 9 Chair: Miguel Soriano moderator: Rachel Jones

14:30-15:00 **Experimental Implementation of Ultrafast Recurrent Neural Networks using Reservoir Computing and Semiconductor Lasers – Invited Talk**

Julián Bueno, Joshua Robertson, Matěj Hejda, and Antonio Hurtado
Institute of Photonics - SUPA Dept. of Physics - University of Strathclyde