

O-band GaAs Quantum Dot Optical Amplifier Integrated on an Advanced SiN Platform

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Abstract: We present an O-band GaAs optical amplifier integrated on an advanced SiN platform using micro-transfer printing. A polycrystalline Si layer facilitates light coupling between GaAs and SiN, resulting 5 dB on-chip gain at 1300 nm.

Keywords: Si photonic and heterogeneous platform, Optical amplifiers, Photonic integration

I. INTRODUCTION

Silicon photonic (SiPh) integrated circuits enable the development of highly miniaturized and scalable optical systems on a single chip. Among different platforms, silicon nitride (SiN) has gained increasing attention due to its ultra-low waveguide loss, broad transparency window, and compatibility with complementary metal-oxide-semiconductor (CMOS) fabrication processes. The continuous advancement in SiN photonic integrated circuits (PICs) has led to their commercialization in foundries, offering a range of high-performance components. Despite these advantages, the lack of essential active functionalities, such as optical amplifiers and on-chip light sources, remains critical for realizing a comprehensive integrated SiN ecosystem. To address this limitation, various integration strategies have been explored, including flip-chip bonding, pick-and-place micro-assembly, die-to-wafer bonding, micro-transfer printing, and heteroepitaxial growth. Among these, micro-transfer printing (μ TP) has emerged as a promising technology for wafer-scale heterogeneous integration with high precision and scalability. [1] However, achieving efficient optical coupling between SiN waveguides and III-V gain materials remains a key challenge compared with traditional III-V/Si integration. Direct evanescent coupling is impractical due to the large refractive index mismatch between SiN and III-V. To mitigate this issue, recent studies have demonstrated the use of an intermediate Si layer as an index-matching layer in III-V/Si/SiN structures, effectively solving coupling issues. [2, 3]

In this work, we developed an advanced SiN photonic platform comprising two SiN layers and one polycrystalline silicon (poly-Si) layer. A three-stage adiabatic taper structure was designed to enable efficient optical coupling between the lower SiN layer and the poly-Si layer. To validate the functionality of the poly-Si layer, we integrated a prefabricated GaAs quantum dot (QD) optical amplifier using micro-transfer printing, under license from X-Celeprint, Ltd. The resulting device exhibits a differential resistance of 3 Ω at a bias current of 110 mA and achieves an on-chip gain of 5 dB at a wavelength of 1300 nm. Moreover, the developed poly-Si module is fully compatible with Ligentec's AN800 SiN production line. The commercialization potential of this poly-Si module paves the way for fully integrated, high-performance SiN PICs with active components.

II. ADVANCED SiN PLATFORM

Since there is a significant refractive index mismatch between SiN (~ 2.0) and GaAs quantum dot material (~ 3.4), direct optical coupling would require an extremely narrow taper tip to achieve phase matching, which is impractical in fabrication. To overcome this challenge, an intermediate layer is necessary. In this work, we focus on poly-Si as the intermediate layer. For rapid validation, we limited the fabrication to three main device layers. The SiN platform under development consists of two SiN layers: the bottom X1 layer, with a thickness of 800 nm, and the upper X2 layer, which is 200 nm thick. A 360 nm poly-Si layer is deposited above the X2 layer, separated by a 100 nm SiO₂ intermediate layer, which has the same thickness as the oxide between X1 and X2. To achieve efficient light coupling between the X1 and poly-Si layers, a three-stage adiabatic linear taper was designed based on eigenmode expansion simulations. Simulations indicate that a transmission efficiency of 97.9% can be theoretically achieved at the O-band. The X2 layer can serve as a transition bridge, significantly reducing the entire taper length from several millimeters to a compact 190 μ m.

III. FABRICATION AND INTEGRATION OF GAAS AMPLIFIER

Following the well-established GaAs process flow described in our previous work [4], a new batch of GaAs quantum dot (QD) coupons was fabricated in dense arrays on its native substrate, as shown in the microscope image in Fig. 1(a). The coupons were undercut by selectively wet etching the AlGaAs sacrificial layer, making them ready for μ TP integration. Fig. 1(b) schematically illustrates the μ TP process. A pre-fabricated GaAs coupon, 1660 μ m in length, was

picked up using a PDMS stamp featuring a single post with matching dimension of 1700 μm in length. After picking up, the GaAs surface was smooth and defect-free, indicating high fabrication quality and precise process control. To provide adhesive bonding force during printing, a thin DVS-BCB layer (~ 50 nm) was spin-coated onto the SiN PIC before placement. The transfer printing was carried out at room temperature in the cleanroom of Ghent university, using a lab-scale μTP tool (X-Celeprint μTP -100). After printing, a few post-processing steps left, including photoresist removal, BCB curing, and final metallization. More details on the μTP process can be found in reference [1].

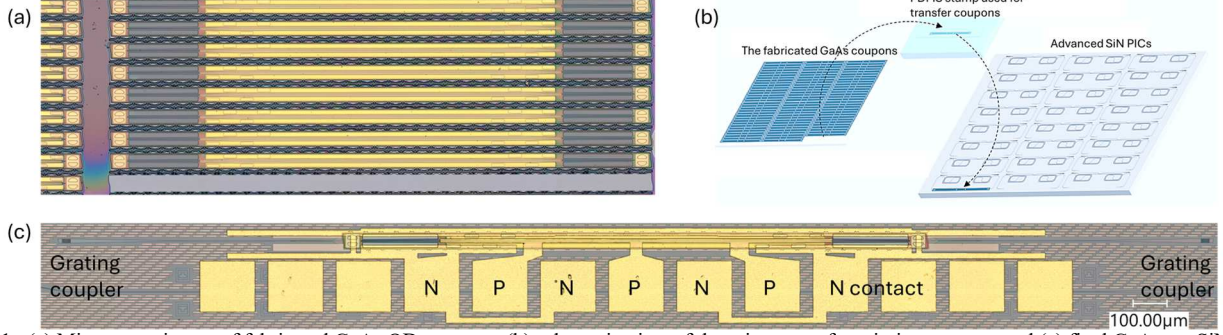


Fig. 1. (a) Microscope image of fabricated GaAs QD coupons, (b) schematic view of the micro-transfer printing process, and (c) final GaAs-on-SiN optical amplifier after metallization.

Fig. 1(c) shows the final micro-transfer-printed optical amplifier after metallization. It's consisted of two identical grating couplers (GCs) on each side with the GaAs coupon positioned in the center. The n and p contact pads were alternately spaced to ensure uniform current injection. Lateral misalignment between the GaAs coupon and the underlying poly-Si waveguide was checked to be less than 200 nm, excluding the coupling losses due to print inaccuracy.

IV. DEVICE CHARACTERIZATION

The GaAs QD-on-SiN amplifier was characterized on a temperature-controlled stage set to 18 $^{\circ}\text{C}$. Optical probing was realized by using cleaved standard single-mode fibers held vertically with an offset angle 7 $^{\circ}$. The amplifier was driven by a Keithley 2401 current source, while fiber-coupled light was fed into an HP 8153A power meter. As illustrated in Fig. 2(a), the measured current-voltage (I-V) curve exhibited a differential resistance of 3 Ω at a bias current of 110 mA. Two identical GCs on the left and right showed very similar current-light (I-L) curves, as expected.

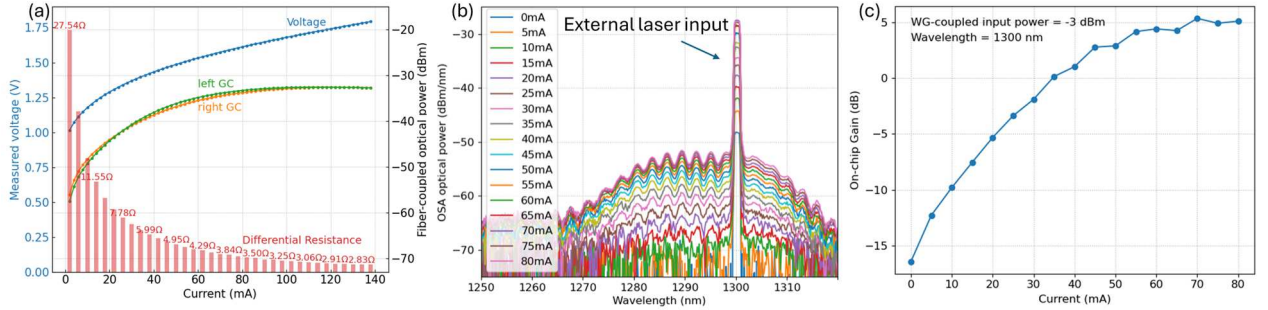


Fig. 2. (a) Light-Current-Voltage curve with calculated differential resistance, (b) amplified spontaneous emission spectra under different current, and (c) measured on-chip gain as a function of bias current at 1300 nm

To assess on-chip gain, light from an external tunable laser (Santec TSL-510) was passed through a polarization controller before being coupled into the device via a GC. The output spectrum was recorded using an optical spectrum analyzer (OSA, Yokogawa AQ6375). Fig. 2(b) presents the amplified spontaneous emission (ASE) spectra at various bias currents. The observed ripples are attributed to the GC design which was not optimized for the current stack, leading to higher order mode excitation. To enable power calibration, optical fiber losses and GCs transmission response were characterized using adjacent reference passive SiN waveguides. The signal output power was measured within 1 nm around the signal wavelength to exclude ASE from the gain calculation. Fig. 2(c) shows the small-signal on-chip gain at 1300 nm under a -3 dBm waveguide-coupled input power. The amplifier becomes transparent at a bias current of 35 mA. The on-chip gain increases with the bias current and reaches 5 dB at 70 mA, after that it shows a thermal roll-off behavior.

V. CONCLUSIONS

In this work, we have demonstrated an advanced SiN photonic platform integrating a micro-transfer-printed GaAs quantum dot optical amplifier. The developed platform features a three-layer architecture with two SiN layers and a poly-Si layer, enabling efficient optical coupling through a three-stage adiabatic taper structure. Experimental characterization confirmed a differential resistance of 3 Ω at 110 mA and an on-chip gain of 5 dB at 1300 nm, validating the effectiveness of the poly-Si strategy. The proposed poly-Si module is fully compatible with Ligentec's AN800 SiN production line, opening avenues for commercial adoption. In addition, this study underscores the potential of micro-transfer printing as

a scalable and precise method for heterogeneous integration, paving the way for the next generation of high-performance SiN-based photonic integrated circuits.

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