Grating Coupled Laser (GCL) for Si Photonics

Shiyun Lin*, Ding Wang, Ferdous Khan, Jeannie Chen, Alex Nickel, Brian Kim, Yasuhiro Matsui, Bruce Young, Martin Kwakernaak, Glen Carey, Tsurugi Sudo
II-VI Incorporated, 1389 Moffett Park Dr., Sunnyvale, CA 94089
**Shiyun.lin@finisar.com*

Abstract: We report a laser with an integrated grating coupler that emits a large ~30 µm mode through its substrate. The GCL allows coupling to a corresponding grating in the Si PIC and insertion of an optical isolator without lenses. © 2020 The Author(s)
OCIS codes: (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits.

1. Introduction

Coupling light from laser to Si is challenging due to the small mode sizes, disparate yield and reliability, and the need for an optical isolator in between, delaying wide spread adoption of Si Photonics in data communications. Heterogeneous laser integration alleviates the alignment of InP and Si waveguides, has low coupling loss and is very compact [1]. However, it reduces the very high yield of the Si photonic circuit to the single-mode and burn-in yields of the lasers, which tend to be much worse than that of Silicon. The bonding of InP on Si is also not widely available as it is not in the tool kits of CMOS fabs. Flip chipping a laser and direct butt coupling to a Si waveguide is a complicated process requiring mechanical precisions of ~ 200 nm, and control of solder volume [2]. Also, individual InP die must be burned in after attachment to the Si PIC, if burn-in is required, potentially reducing yield of the resulting assembly. In addition, neither heterogeneous integration or butt-coupling allow insertion of an optical isolator between laser and the Si circuit. An optical isolator may be needed to achieve the low RIN for 400Gb/s and higher rates or for coherent communications in which the laser linewidth is extremely sensitive to external back reflection. Laser in Si micro-package (LaMP) allows separate yield and burn-in of the laser and insertion of an isolator [3], but still requires the Si package and micro-optics assembly and is difficult to miniaturize due to the working distance of the lens needed to magnify the laser mode to match the Si grating in the PIC.

Here we report a monolithic InP DFB laser with an integrated diffraction grating which generates a large ~ 30 µm beam spot and couples the light through its substrate. The resulting small ~ 3° divergence angle of the GCL allows direct coupling to a receiving grating in the Si PIC with ~ 2-3 µm placement accuracy and the insertion of an optical isolator without lenses with 4-5 dB loss. Importantly, the GCL die can be mounted on a simple substrate, individually tested and burned in before assembly on the Si PIC.

2. GCL design and simulation

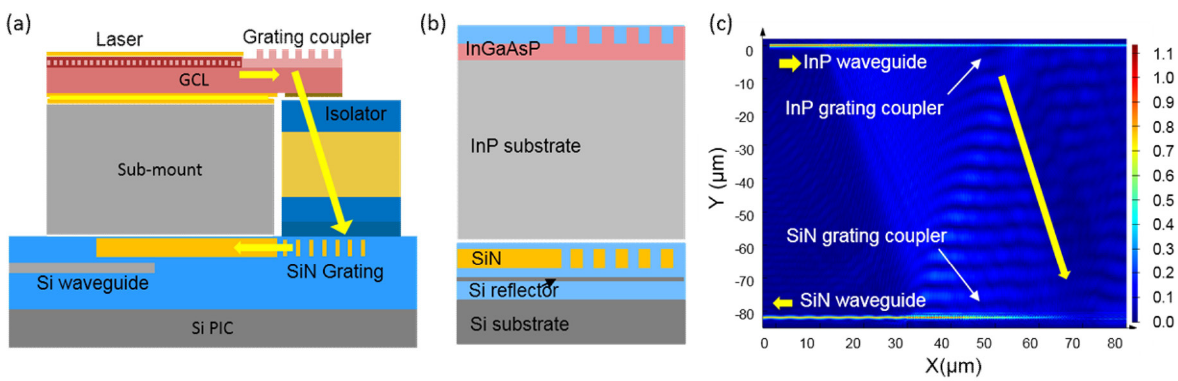

Fig. 1. (a) The GCL, Si PIC stack with an optical isolator, (b) 2D FDTD simulation setup and (c) optical field distribution of the InGaAsP grating to SiN grating coupling through an 80 µm InP substrate, total grating to grating loss is 2.4 dB.

Fig. 1(a) shows a schematic of the GCL coupling to the Si PIC. The output of the GCL through the InP substrate passes through the optical isolator and couples to a SiN grating on a Si PIC. Light from the SiN waveguide is adiabatically coupled to a Si waveguide on the PIC with low loss. Parallelism of the InP top and bottom surfaces, a thin metal bond between laser and sub-mount and mechanical stand-offs in the Si or AlN sub-mount guarantee the small 0.3° required angle assembly tolerance demanded by the large ~ 30 µm laser mode. A heat sink connected to the top of the sub-mount (not shown) removes heat from laser.

The InGaAsP grating to SiN grating coupling efficiency is simulated by 2D FDTD as shown in Fig. 1(b). Here the top waveguide is 300 nm thick InGaAsP with n = 3.39 on an 80 µm InP substrate. Grating teeth with a 300 nm thickness and a 540 nm pitch protrude above the waveguide and covered by SiO_2 top cladding. The bottom SiN waveguide is 600 nm thick with SiO_2 top and bottom cladding, and the SiN grating is fully etched with a pitch of 568 nm. A thin 50 nm Si layer 400 nm below the SiN layer functions as a partial mirror to improve the directionality. Both the InGaAsP and SiN gratings were apodized for optimum coupling. Fig. 1(c) shows the optical field distribution in the simulation. The simulated grating-to-grating loss from InP waveguide to SiN waveguide was 2.4 dB. A statistical analysis that included the distributions of fabrication parameters for both InP and SiN, misalignment, and temperature variation showed the total loss from active section of the DFB to the Si waveguide to be 4 dB to 5.4 dB with an optical isolator and 3 dB to 4.6 dB without an isolator between 0° to 80° C for an uncooled laser.

3. GCL fabrication and performance

The GCL was fabricated by a butt-joint process to integrate a passive waveguide with a laser active epi. Fig. 2(a) shows a top image of the GCL device mounted on an AlN sub-mount. The GCL contains a 900 µm DFB active section and a 300 µm passive section with a diffractive grating. The passive waveguide comprises two 300 nm thick InGaAsP layers with a 30 nm InP layer in between. The quaternary layers have a photoluminescence peak at 1170 nm. Curved diffraction grating is then defined by ICP dry etch. The top InGaAsP layer in front of the grating is removed at the same etching step. Fig. 2(b) shows the top and cross-section SEM image of the curved grating. Next, InP p-cladding layer is selectively grown on the laser section, followed by a simple ridge waveguide process to define the lateral optical confinement in both sections simultaneously. Backside AR coating is then deposited underneath the grating region, after top and bottom contact metal processes. The front and back cleaved facets are coated with AR and HR coatings respectively.

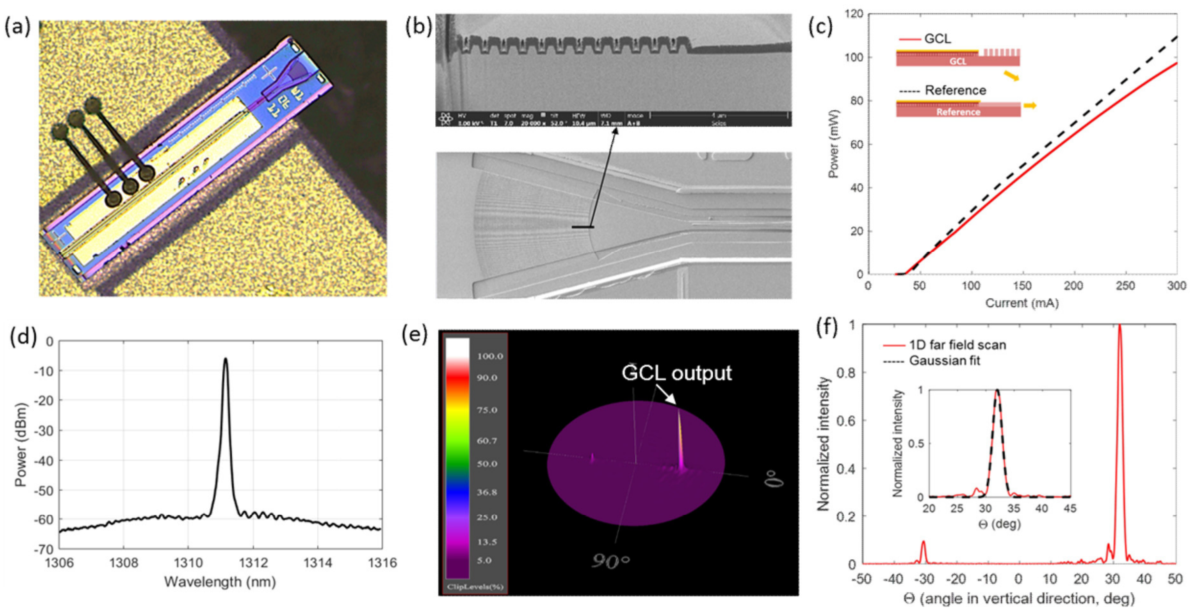

Fig. 2. (a) GCL on a submount, (b) top view (bottom) and a FIB cross-section view (top) SEM image of the grating coupler, (c) L-I curves of the GCL and a reference DFB laser without the grating coupler, (d) lasing spectrum of the GCL, (e) 2D far field intensity measured by a Goniometer, (f) 1D far field profile at $\varphi = 0$, a Gaussian fitting of the main peak is shown in the inset.

Fig. 2(c) shows typical L-I curves of a GCL and a reference laser measured on bar tester in cw condition at TEC = 25°C. The reference laser has the same laser section integrated with a passive waveguide instead of a grating coupler. A large area detector is used to collect the laser output of each device in the direction denoted by the arrows in the inset. The slightly smaller power of GCL comparing to the reference is due to the upward diffraction from the grating, which was not collected by the large area detector. Fig. 2(d) shows a typical lasing spectrum of the GCL with a side mode suppressing ratio > 50 dB. The far field pattern of the GCL is characterized by a Goniometer. Fig. 2(e) shows the 2D intensity pattern of the GCL in polar coordinates with a narrow peak at θ = 32° to the horizontal exiting from the substrate. Note that a standard edge emitting laser would have produced a 20° to 30° wide peak centered at θ = 0. Fig. 2(f) shows the 1D far field intensity profile at φ = 0. The main peak of the GCL has a divergence angle of 3.2° in θ direction and 3.8° in φ direction, which corresponds to a mode field diameter of 30 µm x 25 µm. The weaker narrow peak observed at θ = -32° is the aforementioned upward diffracted beam, which is 10 dB lower than the downward diffracted beam. A Gaussian curve fitting and integration shows 80% of the power in the main peak or a 1 dB diffraction efficiency.

4. Coupling between GCL and Si PIC

The GCL on a sub-mount was actively aligned to a SiN receiver grating on a CMOS Si PIC. A latched isolator composed of a 330 µm thick garnet and a 76 µm thick half wave plate was inserted between the GCL and the receiver grating. The polarizers were omitted since the grating couplers function as polarizers. The output of the SiN grating is directed by a low loss U-shaped SiN circuit to the opposite side of the Si PIC and collected by a lensed fiber. The Si PIC was fabricated in ST Microelectronics' 300 mm process which offers a PECVD SiN layer with minimum spaces of 200 nm allowing formation of large mode SiN gratings for coupling to GCL [4]. The SiN grating is defined on a fully etched 350 nm SiN layer with a 50 nm Si underneath it as a reflector. A straight uniform grating was used in this experiment. The GCL is powered by a Keithley 2520 pulsed laser diode testing system with a 1% duty cycle to minimize the heat. Fig. 3(a) shows the measured power coupled into the SiN waveguide. The reference laser power is measured by coupling the GCL directly to a multimode fiber. The GCL to Si PIC coupling loss shown in Fig. 3(b) is calculated by dividing the power in the PIC by the reference laser power. A GCL to Si PIC coupling loss of 6 dB is measured above the laser threshold. The isolator used in this experiment does not have an AR coating and therefore contributed an extra ~2 dB loss due to the reflection at the air/garnet surface. With a proper AR coating, the GCL to Si PIC coupling loss is expected to be 4dB. Note that both grating couplers used in this experiment are not apodized. The 600 nm fully etched SiN grating design with Si 'mirror' used in simulations of Fig. 1(b) with a GC-GC loss of 2.4 dB was not available for this demonstration. Fig. 3(c) shows 1dB grating to grating misalignment tolerance of ±7 µm in lateral direction and ±10 µm in longitudinal direction. For a target misalignment loss <0.2 dB, it can tolerate a +/- 2-3 µm misalignment. The large misalignment tolerance relaxes alignment accuracy requirement and pave to the way for passive alignment.

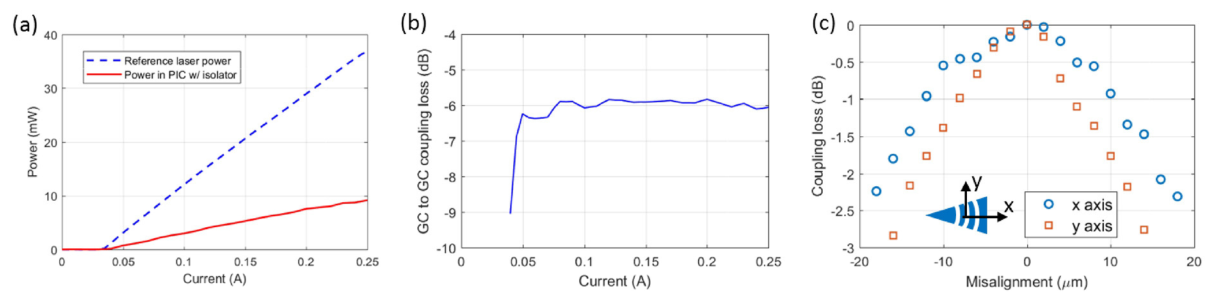

Fig. 3. (a) L-I curves for the optical power coupled into the SiN waveguide on the PIC and the reference laser power directly measured from the bottom of GCL, (b) GCL to SiN waveguide coupling loss, (c) misalignment tolerance for the grating to grating coupling

5. Conclusion

We have demonstrated a grating coupled laser by integrating a high-power DFB laser with a passive diffractive grating. The GCL emits a beam with divergence angle of 3.2° in vertical direction and 3.8° in horizontal direction. The small divergence angles can accommodate an isolator before coupling to a SiN receiver grating on a Si PIC. A coupling loss of 6 dB from GCL to Si PIC was measured with 2 dB loss from the non-AR coated isolator. The grating to grating coupling has a measured 1dB misalignment tolerance > ±7µm.

References

[1] W. Fang et al., "Electrically pumped hybrid AlGaInAs-Si evanescent laser," Optics Express **14**(20), 9203-9210 (2006).
[2] T. Barwicz et al., "Automated, high-throughput photonic packaging," Optical Fiber Technology **44**, pp. 24-35 (2018).
[3] Peter De Dobbelaere, ECOC 2014 WS1: http://www.ecoc2014.org/sunday-workshops.html#ws1
[4] C.Baudot et al., "Developments in 300mm silicon photonics using traditional CMOS fabrication methods and materials," International Electron Device Meeting, IEDM 2017 pp. 34.3-1 to 34.3.4.