Abstract—We demonstrate the integration of vertical-cavity surface-emitting lasers (VCSELs) with silicon photonics chip using flip-chip bonding technique, with bidirectional vertical-coupled grating coupler for light coupling.

I. INTRODUCTION

One of the most important remaining issues faced by the silicon photonics community is the on-chip laser source. Potential solutions fall into two categories. One is heterogeneous integration by direct wafer bonding or epitaxial growth, the other is hybrid integration of silicon photonics chips with III-V epitaxy on laser chips. Heterogeneous integration has challenges related to crystal properties and fabrication process, whereas the hybrid solution can integrate the optimized silicon photonics chips to best in breed III-V epitaxial laser chips. Due to their surface-normal emission, VCSELs are of great interest for hybrid integration with grating-based off chip couplers in silicon, enabling simple, direct bonding schemes. Enormous progress has been made in VCSEL technology in the past two decades, with various successful attempts at hybrid integration of VCSELs to various carrier substrates [1], [2]. The flip-chip bonding technique has been used to bond both single VCSEL [1] and VCSEL arrays to CMOS chips [3]. However, flip-chip bonding of VCSELs with silicon photonics chips is more challenging than the bonding of VCSELs with CMOS chips. High alignment accuracy is required during the bonding process as the output from the VCSEL needs to be precisely aligned to the vertical grating coupler on the silicon photonics chip. In this paper, we demonstrate the integration of a VCSEL [4] with silicon photonics chip using the flip-chip bonding technique, with custom designed vertical grating couplers as the input/output interfaces. The schematic of the bonding structure is shown in Fig. 1.

II. VERTICAL GRATING COUPLER

A vertical grating coupler is required to couple the light from the VCSEL onto the silicon photonics chip. Such vertical grating couplers have been designed to couple light from optical fibers onto silicon photonics chips [5]. However, the existing vertical grating coupler only couplers light to one side of the coupler, and normally a maximum coupling efficiency of 50% applies due the symmetry of the design. The near-field mode size of the VCSEL is smaller than the mode size from an optical fiber. Therefore, a smaller grating coupler is required, which makes high-accuracy alignment more difficult to achieve for the bonding process. A bidirectional vertical grating coupler is designed to couple the light from the VCSEL onto the silicon photonics chip. The cross-section along with a microscopic image of our bidirectional vertical grating coupler is shown in Fig. 2. Our vertical grating coupler was designed for silicon-on-insulator (SOI) wafer with a 300 nm silicon layer and a 800 nm buried oxide. A partial etch layer with etch depth of 145 nm was used and the design parameters are shown in Fig. 2(a). As shown in Fig. 1, the output beam from the VCSEL get diffracted at the center of the grating and couples the light equally into the waveguides on both sides of the grating. Adiabatic tapers were used on both sides of the vertical grating coupler to couple the mode from a 6-µm slab mode into a sub-micron silicon-wire waveguide mode. Detuned output grating couplers were connected to both arms of the vertical grating coupler.

III. FABRICATION AND MEASUREMENT

Fabrication of the silicon photonics chip has been done using electron beam lithography [6]. Bond pads were designed for the silicon photonics chip matching the dimensions of the VCSEL pads. 4 µm thick gold traces were deposited on the silicon photonics chip to connect the bond pads to corresponding probe pads far away from the bond pads.
(Fig. 2(b)). Therefore, when the VCSEL is flip-bonded to the silicon photonics chip, we can utilize the pads on the silicon photonics chip to drive the VCSEL. Chips were aligned and bonded using a standard flip-chip bonding process, with a thermally cured epoxy layer for adhesion and gold microsolder pillars for electrical interconnection. A bonding load of 0.8 kg was used.

The comparison of the V-I and L-I curves of the bonded VCSEL, before and after bonding, are shown in Fig. 3. It can be seen from Fig. 3(a) that the driving voltages of the VCSEL increased after bonding to the silicon photonics chip, which is caused primarily by the additional resistance from the pads and metal wires on the silicon photonics chip. Fig. 3(b) shows the power versus current of the bonded VCSEL, before and after bonding. The power after bonded was measured using a large area detector collecting power from two output grating couplers connected to the two arms of the bidirectional vertical grating coupler bonded to the VCSEL. One of the remaining challenges is the control over the polarization state of the output light from the VCSEL. Our vertical grating coupler was designed for TE polarized light with a polarization mode suppression ratio of 20 dB. Due to the polarization uncertainty of the VCSEL and the insertion loss from the input and output grating couplers, the measured power after bonding was much lower (by 13.5 dB) than before bonding. Further improvement can be made using optical feedback from the grating to control the polarization of the VCSEL [7].

IV. CONCLUSION

We demonstrate the integration of a VCSEL with a silicon photonics chip using the high precision flip-chip bonding technique. A bidirectional vertical grating coupler is designed to couple the light from the VCSEL onto the silicon photonics chip. The bonded VCSEL was driven using electrodes on the silicon photonics chip. Light was successfully coupled into single-mode rib waveguides.

REFERENCES