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Authors	Patil, Chirag M.;Hwang, How Yuan;Pfeiffer, Martin;Noell, Wilfried;Morrissey, Padraic E.;O'Brien, Peter
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Microlens-Assisted Expanded Beam Technique for Coupling of Laser Source to Photonic Integrated Circuit

Chirag M. Patil [(1)], How Yuan Hwang[(1)], Martin Pfeiffer[(2)], Wilfried Noell[(2)], Padraic E. Morrissey[(1)], and Peter O'Brien [(1)]
[(1)] Photonics Packaging Group, Tyndall National Institute, Lee Maltings Complex, Cork T12R5CP, Ireland
[(2)] SUSS MicroOptics SA, Rouges-Terres 61, CH-2068 Hauterive, Switzerland
peter.obrien@tyndall.ie

***Abstract*:** Efficient coupling interface is crucial for integrating densely-packed photonic sub-assemblies. This study presents a microlens-assisted expanded-mode technique for coupling light from a laser diode into a photonic-integrated-circuit edge coupler. The results show good coupling with relaxed alignment tolerances, paving the way for efficient free-space optical interconnects in chiplet-based photonic packaging.

1. Introduction

Technology is advancing rapidly, leading to a surge in data generation and transmission. Photonic integrated circuits (PICs) use light instead of electricity to process and transmit data, providing advantages such as faster data transfer rates, lower power consumption, and higher bandwidth. PICs have broad applications, including high-performance computing, wearable biosensors, LIDAR-enabled automobile navigation, and optical communications. As a result, integrated photonics is expected to play a vital role in future innovations [1].

Although silicon is a reliable platform for fabricating many photonic components, its indirect band gap makes it difficult to achieve photon emission. As a result, researchers have devoted significant efforts to exploring alternative materials, such as InP, LNOI, GaAs, SiN, and III-V semiconductors, for creating active elements such as laser diodes, modulators, and optical switches [2]. By integrating multiple chips onto a single platform, manufacturers can greatly reduce the size and complexity of optical systems, resulting in more compact, cost-effective, and efficient devices.

Low-loss coupling between different photonic components, such as light sources, modulators, and detectors, is one of the most significant challenges in photonic integration [3]. This requires accurate mode-matching and precise alignment of the components to minimize the losses at the interfaces between them. Efficient coupling of light from a source into a PIC remains a major bottleneck in realizing the full potential of integrated optical systems. High coupling efficiency is crucial for optimal performance, as it directly affects the amount of optical power available for detection and manipulation.

Off-chip laser sources are those that are separate components, external to the photonic integrated circuit (PIC), but are coupled to the PIC using various techniques such as lensed fibers and tapered fibers. On-chip laser sources, on the other hand, are integrated directly onto the same chip as the photonic devices, offering a more compact and potentially more efficient solution. These lasers can be integrated using different techniques such as monolithic integration, micro transfer-printing, die-to-wafer bonding, and hybrid integration [4,5]. Monolithic integration involves fabricating all the components in a single chip, while hybrid integration involves assembling different photonic components onto a common platform. The choice of integration technique depends on the specific application requirements and trade-offs between performance, cost, and scalability.

2. Expanded-Beam Approach

In this paper, an expanded beam approach to optical coupling using a pair of collimating-refocusing micro-lenses is demonstrated. Figure 1 illustrates this approach, which involves using a convex micro-lens to expand the divergent beam of a laser diode into a collimated beam with a mode field diameter (MFD) of approximately 250 µm. A second lens is then used to refocus the collimated beam towards the edge coupler of the PIC, matching the MFD of the coupler for optimal coupling efficiency.

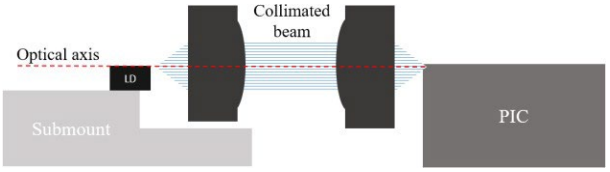


Fig. 1. An illustration of the expanded-beam coupling scheme to direct light from laser diode to PIC edge coupler.

The pair of micro-lenses in this approach serve multiple purposes. Firstly, the expanded beam approach can compensate for lateral and angular misalignments during lens assembly, resulting in relaxed misalignment tolerance for the optical system. Secondly, the micro-lenses collimate and couple the divergent beam from the laser diode to the PIC edge coupler in a free-space environment, enabling the integration of different optical components such as isolators, wave retarders, and beam

splitters in the optical path. Finally, the approach enables the laser diode to couple light into the PIC from a distance, allowing for dedicated thermal management of the laser diode and preventing thermal cross-talk on the PIC. In this demonstration, the distance between the laser and the PIC can be as far as 4 mm.

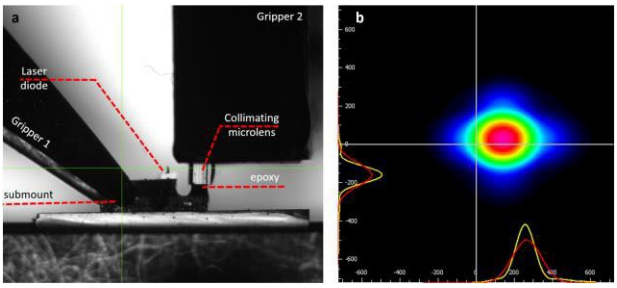


Fig. 2. a) Alignment and fixture of the collimating micro-lens on the laser sub-mount. b) 2D mode profile of the collimating beam (250 µm x 255 µm) measured on the beam profiler at a distance of 1 cm.

Figure 2 illustrates the alignment and assembly of collimating microlens on the laser-diode micro-optical bench. The laser diode is attached using a solder reflow process on a flip-chip bonder, and the collimating microlens is actively aligned and assembled using a UV-cured, high-temperature resistant epoxy (NTT AT3862P). The refractive micro-lenses were designed and fabricated on silicon by SUSS Micro-Optics in Switzerland using their proprietary reactive ion etch technology.

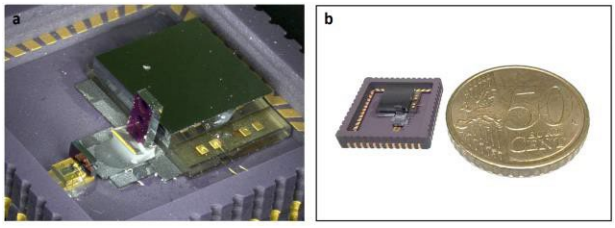


Fig. 3. a) A micro-optics-based coupling scheme is employed for integrating laser source with a reference PIC. The laser beam (4.3 mW) is collimated by the microlens on the laser assembly (4 mW, located on the left), and subsequently refocused onto the PIC edge coupler using the refocusing lens (located on the right). The coupled optical power measured by the on-chip photodetector was 1.3 mW. b) The photonic sub-assembly integrated inside a QFN package (coin for comparison).

For the final assembly of the refocusing micro-lens, an on-chip Germanium photo detector was used to probe and monitor the coupled light. This was done using the active alignment process to achieve maximum coupling efficiency between them. The laser assembly and the refocusing micro-lens were then assembled in position using UV-cured epoxy. The coupled optical power measured by the on-chip photodetector was 1.3 mW when the laser diode produced an output power of 4.2 mW. Notably, the refocusing lens was designed to couple light into a 6 µm MFD edge coupler, while the PIC used in this demonstration had an edge coupler MFD of 3 µm. Therefore, using mode-matched optics, a higher coupling efficiency can be anticipated.

3. Conclusion

In conclusion, the proposed scheme can effectively compensate for undesirable lateral and angular misalignments during the coupling of light from the laser source into a PIC. By designing and fabricating micro-lenses, it is possible to bridge the mode-mismatch between different chiplets, thereby reducing packaging costs and optimizing the process for volume manufacturing. This approach creates new opportunities for further advancements in both laser to PIC integration and co-integration of light between PIC chiplets using free-space.

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