Silicon Based Edge Emitter Packaging Solution

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Abstract

Current packaging solutions for edge emitters rely on multiple steps using different materials and fabrication methods. This often leads to bulky, expensive and complex packaging solutions, consequently limiting their use. Additionally, for large scale manufacturing, wafer-scale packaging is needed to increase the assembly line throughput.

In this paper, a silicon interposer is proposed for integrating an edge-emitting laser, a prism and a lens in a single substrate. Interposers, made of silicon, allow the use of diverse and mature fabrication techniques. Moreover, silicon's excellent thermal conduction enables good heat dissipation, negating the need for added heat sinks in the package.

We propose to process both sides of the silicon wafer. On one side of the wafer, a light-diverting prism can be created. Light emitted by the laser enters the silicon bulk via a wall perpendicular to the beam propagation direction. Once inside the silicon, a 45-degree wall diverts the beam vertically through the wafer via total internal reflection. On the other side of the wafer, a lens can be created to focus the beam into an optical fiber.

We show through modelling that this silicon prism and lens are capable of coupling the edge emitting laser single mode output into a single mode fiber core with minimal losses.

Introduction

The current field of packaging for edge emitting lasers (EEL) uses a multitude of fabrication methodologies that increase the complexity and size of the packaged product [1]. They often lack any sort of focusing or collimating optics in the interposer or laser diode [2], resulting in added bulk as lenses need to be integrated somehow, via another system. Additionally, due to the perpendicular working planes between beam direction from an edge emitting laser and a wafer surface, wafer level packaging and testing of EEL is challenging. As the need for better performance in optical systems arises, a tighter integration of all its elements is needed, to reduce electrical signal RC limitations [3] and energy losses between different focusing optics and packaging elements.

Previously proposed solutions include using mirrors to re-direct light but lack any focusing element [2]. Others have tried to incorporate both a mirror and a curved surface into a photoresist greyscale structure [4] but are using a fiber coupled to a waveguide and not a laser chip. Solutions with chip bonding exist but resort to lens manufactured separately and bonded to the substrate [5].

In this paper we propose a wafer level silicon interposer with a monolithically integrated prism and lens, optimized for EEL packaging. By designing the lens as an aspherical circular shape and using a close to ideal anti reflective (AR) coating, we can achieve mode coupling efficiencies higher than 95% between the EEL emitted mode and a single-mode fiber (SMF) core, for circular and elliptical laser beams. A clear advantage of this approach is that light interfaces only with one optical element, avoiding losses between extra interfaces. This continuous prism design is also advantageous when it comes to polarization or wavelength handling. As long as the wavelength of the laser is in the range where material absorption in silicon is negligible (>1100nm), this bulk structure will transmit, redirect and focus light regardless of polarization or wavelength. Moreover, this design can reduce the traditional packaging complexity of edge emitting lasers by transforming it into a wafer level packaging process.

Methods

To simulate the proposed prim (Fig. 1), Ansys Zemax OpticStudio 2023 was used. Using its Sequential Mode and Fiber Coupling Integral tool, the prism was optimized to obtain the best mode coupling efficiency into a fiber core with a 5µm gaussian waist, following the chief ray. For this simulation, a standard silicon wafer is assumed with a thickness of 500µm. For this, the SILICON material in the INFRARED catalog of Zemax is used.

As light sources for the model, two beam settings were used to validate this prism. One is an ideal circular beam with 1550nm of wavelength and 35 degrees of Gaussian angle, in both X and Y. Another was an elliptical beam based on a commercial DFB Laser chip with a wavelength of 1371nm and a Gaussian angle in X of 26 degrees and in Y of 37 degrees.

To compensate for the high Fresnel reflections between air and silicon, the ideal Zemax coating I.995 was used (99.5% of all light gets transmitted).

The lens data starts with a thickness of 3µm until the first silicon surface. This first silicon surface has no curvature and stretches for 5µm. A coordinate break (a surface that assumes the previously defined refractive index) is then defined with a 45 degree tilt about X. Beyond the 45 deg wall, a mirror surface is defined with an ideal coating having 100% reflectance and 0% transmission. A new coordinate break is defined following this mirror with another Tilt About X of 45 degrees but this time, it has a thickness of -500µm, to simulate the entire wafer thickness. A final surface is defined as an even asphere, that has its 4^{th}, 6^{th} and 8^{th} order sag coefficients, along with its thickness and radius set as variables, to be optimized for best mode coupling efficiency.

The optimization for these variables was carried out in a staggered manner, using the POPD Merit Function to obtain the maximum mode coupling efficiency into the fiber.

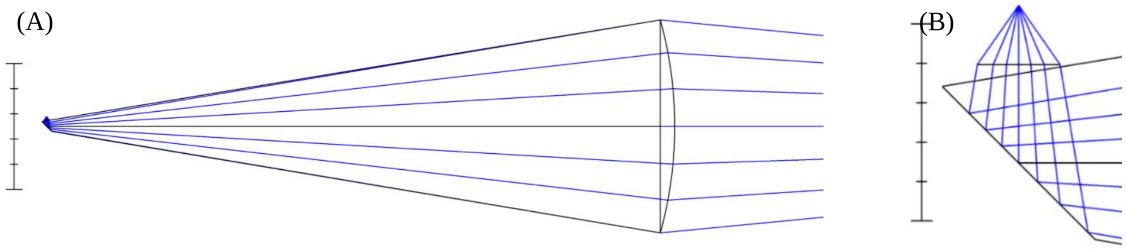

Fig. 1 - (A) Zemax 3D model of simulated prism (0.1mm scale bar), (B) Detail of 45 degree mirror (0.01mm scale bar).

Results

Initial simulations of back reflections without any coatings showed the expected power loss from Air-to-Silicon-to-Air transmission (approximately 30% per interface). The detector surface shows a total power of 48%, for both circular and elliptical beams. Using the ideal anti-reflective coating I.995, the total power detected was 99%.

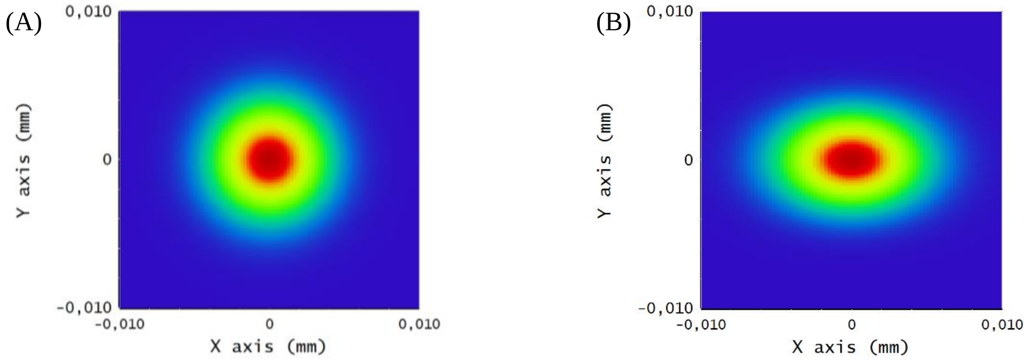

Fig. 2 - (A) Circular beam profile at fiber core, (B) Elliptical beam profile at fiber core.

As to mode coupling efficiency, for the circular beam, the optimized parameters obtained were a radius of 0.317mm, a distance from the lens to the detector of 1.043mm, and the 4^{th}, 6^{th} and 8^{th} order sag coefficients as -0.599, -47.519, 614.037 respectively. These values result in a 99.8628% mode coupling efficiency (Fig. 2 (A)). For the elliptical beam, the optimized parameters obtained were a radius of 0.315mm, a distance from the lens to the detector of 1.016mm, and the 4^{th}, 6^{th} and 8^{th} order sag coefficients as -1.997, 33.192, -970.405 respectively. These result in a 95.0397% mode coupling efficiency (Fig. 2 (B)).

These results show that with only one optimized aspherical lens for each beam, a mode coupling efficiency higher than 95% can be realized with our structure.

Additionally, a tolerance study has been done on potential packaging issues such as the silicon etch wall angle variations from the ideal 90 degrees or the misalignment of the output fiber. Taking the ideal circular beam and varying the first silicon wall angle, while maintaining the fiber in a fixed position shows a drop of less than 10% of mode coupling efficiency at a 2 degrees shift (Fig. 3 (A)). At 5 degrees, the mode coupling efficiency drops 40%. Positive and negative angle variations show symmetric drops. However, if this simulation is repeated with the fiber following the Chief Ray, the coupling efficiency never drops below 98%, which indicates that wall angle deviations from fabrication imperfections can be compensated with active alignment during fiber packaging. Fiber decentering shifts show a similar drop. A 1µm shift in the X axis shows a drop to 96% mode coupling efficiency (Fig. 3 (B)). This is an achievable result using assisted alignment techniques [6].

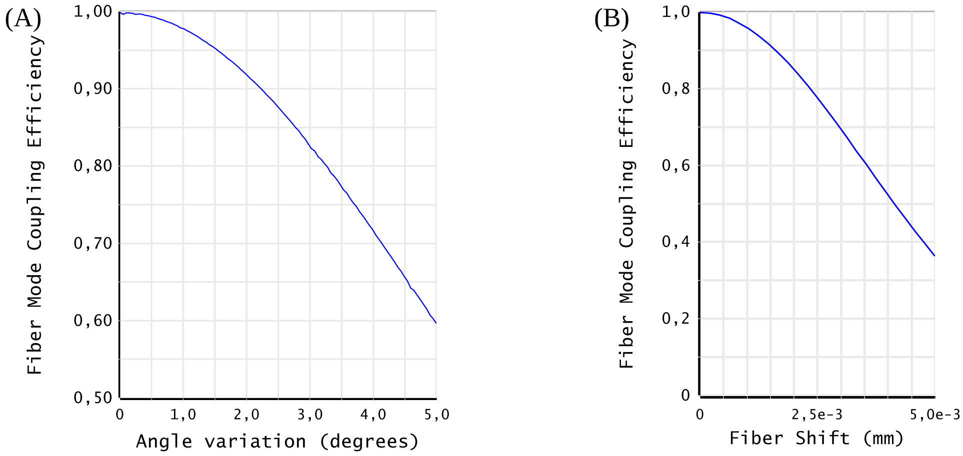

Fig. 3 – Ideal Circular beam Fiber Mode Coupling Efficiency variation per silicon wall angle shift (A) and per fiber shift in the X axis (B).

Discussion

We show that the proposed interposer prism has the potential to integrate an edge emitting laser and a lens in a package that minimizes energy losses and maximizes the mode transfer into a fiber. While the mode coupling efficiency drops significantly with variations of wall angles for a fiber core in a fixed position, or by shifting the fiber core, they can be mitigated by adapting the fiber to be lensed or have an expanded core.

For the ideal scenario, of a circular beam with a circular lens, we get a near total fiber mode coupling efficiency. It drops, however, with an elliptical beam, as the circular lens does not circularize the beam for the fiber core. We believe there is a possibility to use freeform lenses, that can circularize a beam at a defined focus point. Likewise, lenses can also be made to collimate the beam, be it circular or elliptical.

Furthermore, all of the shapes needed for this prism to work are obtained with current silicon fabrication processes. The smooth silicon vertical wall is possible with a cryogenic etching process [7]. The 45 degree mirror is made with a mixture of KOH and Triton X-100 [8]. The lenses can be drawn with greyscale lithography [9] and etched into silicon. To create the anti-reflective coating, an LPCVD process can be tuned to get the right refractive index and thickness [10].

Acknowledgements

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