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Invited

Silicon Micromachined Microphotonics

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This paper describes a revolutionary, yet practical, approach to packaging of optoelectronic modules. This approach calls for abandonment of the traditional approach to optoelectronic packaging, that of permanent, precise placement of various optical components inside the module, which must withstand environmental and aging factors in field operation. Instead, microactuators inside the *adaptively-packaged* module provide continuous, optimal alignment of the optical components. The control signals fed back to the microactuators are derived from monitoring one or more key performance parameters of the system. This new approach is more affordable than those presently in production, because it replaces the active monitoring/alignment procedure now taking place on the manufacturing floor (often performed manually) by batch-manufacturing procedures. The precise alignment needed for high-performance modules will be accomplished automatically in the field under electronic servo control.

A conventional laser-transmitter module involves essentially three to four optical components - the laser chip, the fiber pigtail, an optical isolator and microlens for beam collimation. In low-end products, the optical isolator and microlens are omitted, and the proper alignment between the laser chip and the fiber pigtail is determined primarily by the highest coupling efficiency. This typically requires a relative alignment precision of 1-2 μm. It is important to note that there exists a trade-off between peak coupling efficiency and alignment sensitivity: if the fiber-tip is prepared so that it forms an optimal short-focal-length lens, then the coupling efficiency can be as high as 80-90% but the position sensitivity is in the low-submicron range. This is undesirable or unattainable in a manufacturing environment, so a nonoptimal fiber-tip lens is used which reduces the maximum coupling efficiency to only 10-20% but allows for a much broader tolerance in position. Low-end products therefore can be manufactured by the so-called "passive" alignment technique, where components are put down on a common substrate (often silicon) and positioned using photolithographically defined solder pads and (micro)mechanical stops and guides. (This is the so-called "silicon-optical-bench" technology.)

For high-end products, requirements for low noise and low distortion necessitate the inclusion of micro-optical isolators between the laser chip and the fiber-pigtail in the package. The relatively large separation between the laser and the fiber requires an optical design involving a pair of collimating and refocussing lenses. Often, these modules (such as those used in CATV transmission) also require high coupled power in order to maintain a high signal/noise ratio for the transmission link so that the alignment sensitivity remains highly critical. The packaging of these components can only be done, at considerable cost and throughput degradation, using active monitoring during fiber-alignment. Part of the cost comes from the requirement that the "optimal" packaging alignment is maintained after the module leaves the manufacturing floor.

Micromachined microphotonics provides a technology whereby movable micro-reflector elements can be built inside the package to carry out optical alignment, using feedback-control subject to an algorithm derived from several monitored performance parameters, such as signal distortion, noise and coupled power. The micro-reflector has two-dimensional degree of freedon in its motion, can be actuated with an on-chip micromotor, and performs the alignment task on a continuous basis while the laser module is operating in the field, the same function now carried out by an operator on the manufacturing floor. These new components eliminate the active alignment step now required in the manufacturing process. We call this *adaptive packaging* technology. The various optical components as well as the microreflector are assembled into the laser module and "loosely" pre-aligned using passive alignment techniques, enabling parallel batch processes to be used during manufacturing. In this way *adaptive packaging* technology leads to a lower-cost, affordable high-performance optoelectronic module.

The external cavity laser (ECL) is another example of a large bulk optical instrument whose high cost, large size and weight limits its applicability and market size. In the CATV module we considered coupling between a laser or other optical component with a relatively small waveguide and an optical fiber with a mode diameter on the order of 10 μm. In the ECL, shown in Fig. 1 below, a related, but more complex, problem occurs when light must be coupled from the small cross-section waveguide of the laser into the external optical system and back into the laser. The tuning of the laser imposes additional requirements on the range of motion and position accuracy of the microreflector.

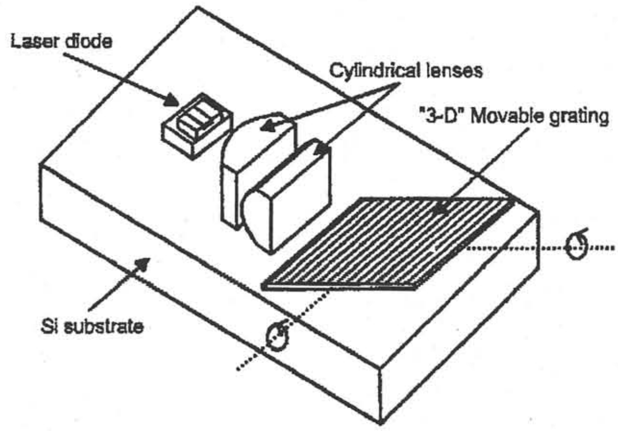

Figure 1. Tunable external cavity diode laser (ECL) consisting of a semiconductor gain medium, a crossed pair of cylindrical lenses and a moveable micromachined grating.

The enabling technology for this type of "tunable laser on a chip", is again the movable microreflector, which in the case of Fig. 1 is equipped with a grating rather than a flat surface. The microreflector is similar to the one used for active alignment, but the mechanical requirements are different. The position accuracy of the reflector is on the order of 0.1 μm to ensure efficient coupling back into the laser. The range of motion is dependent on the required wavelength tuning range, but will typically be on the order of several hundred μm. The size of the ECL microreflector is also significantly larger than that used for active alignment. To interact with the 200 μm diameter beam at an incident angle of 80 deg., the reflector has to be 800 μm long. In addition to these requirements on mechanical size, range of motion and accuracy, the microreflector for the ECL on a chip, like the one used in alignment, must be technologically compatible with the silicon-optical bench and conventional integrated circuit technologies

This talk will discuss in detail recent progress in silicon micromachined microphotonics technology, which includes fabrication technologies involving silicon microhinges and comb-driven microvibromotors, as well as the optical performances of the microphotonic system.