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ABSTRACT

Examples are presented of the application of Lawrence Livermore National Laboratory's expertise in photonics packaging. Several examples of packaged devices will be described. Particular attention is given to silicon microbenches incorporating heaters and their use in semiconductor optical amplifier fiber pigtailling and packaging.

Keywords: Silicon microbench, silicon heaters, poly-silicon, packaging, pigtailling, semiconductor optical amplifier.

1. INTRODUCTION

Over the past half decade there has been a growing awareness of the capabilities of opto-electronic multi-chip modules. There are vast markets developing in a diverse range of applications, including local area networks, computer interconnects, and fiber to the home, for example. However, the costs are presently too high to allow these markets to fully realize the potential of fiber optics. To a large extent, cost of the components packaging will determine how these markets develop. Silicon microbenches with on-board heaters, on which optical components such as modulators, lasers, optical receivers, waveguides, optical amplifiers, etc., are integrated with micro-electronic circuits and pigtailed to optical fibers, are one approach to these modules. Lawrence Livermore National Laboratory is working to develop the technological promise of these devices, as well as address the issue of making their use an economically viable choice.¹

There are a number of advantages and difficulties associated with the use of silicon microbench designs. A variety of microbenches, designed to emphasize certain advantages, and overcome the disadvantages, are being developed at LLNL as well as at other facilities such as Bell Labs², and GTE³, to mention just a few. Following is a summary of these advantages and disadvantages.

2. ADVANTAGES OF SILICON MICROBENCHES WITH HEATERS

Silicon, by virtue of its surface finish and suitability for metallization is ideal for mounting lasers and other optical semiconductors with their active regions adjacent to the substrate (active layer down or flip-chip mounting). Flip-chip mounting can then take advantage of silicon's good thermal conductivity, about 160 W/m-°C, nearly that of aluminum.

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Designs can take advantage of the well developed silicon fabrication technology which allows manufacture of features to tight tolerances. Custom features on the microbench result in few, if any submounts.

Poly-silicon layers can be grown with controlled resistances (10-100 ohm-cm), for use as on chip heaters. Silicon also allows the growth of insulating layers.

On board heaters allow the controlled application of heat at specific locations. As a result the components are subjected to a minimum of thermal stress. More importantly, the application of heat is very fast, especially when using pulsed techniques, resulting in minimal thermal expansion. (see Fig. 1 and Fig. 2) As a result these benches provide the capability of maintaining sub-micron alignment tolerances necessary for single mode fiber pigtailed operations.

There are additional advantages which become important in specific designs such as the following. Packaging of the laser and drive electronics in a common transmitter module for high speed is facilitated. Geometries that are compatible with automated processes are readily available. Multiple heaters on a bench allows multiple step soldering of devices. Heaters can be used more than once, for localized rework. Hermetic designs are possible, free from epoxies.

3. DIFFICULTIES ENCOUNTERED WHEN USING SILICON MICROBENCHES

A list of issues which need to be addressed when using these devices would include the following. Fiber movement during solder reflow must be minimized and carefully characterized. Unanticipated current paths may occur in the microbench if conduction and insulation patterns are not carefully designed and fabricated. These parasitic resistances can cause unforeseen heating. Low temp solders are required that are compatible with gold contacts. It is difficult to prevent oxidation of solder without the use of fluxes. Fumes from fluxes can damage optical devices. Assembly processes are not yet adequately characterized to the degree necessary for a commercial manufacturing process. Finally, there is potential for excessive strain on components made of III-IV semiconductors due to differences in thermal expansion coefficients. (Soft solders help relieve these strains.)

4. SILICON MICROBENCH TECHNOLOGY AT LLNL

4.1 Overview

The thrust of the work described here is based on active alignment techniques, in contrast to passive alignment techniques, such as silicon V-grooves, precision static positioning structures, or alignment fiducials. Our belief is that active alignment, if automated, is neither labor intensive nor expensive, and is clearly the best way to get sub-micron alignments for single mode fibers.

At LLNL we initially became interested in silicon microbenches to pigtail high power 800 nm laser diodes to single mode fibers. Our original concept was to allow soldering of fibers with a minimum of movement during the attachment operation. Minimal heating means minimal thermal expansion.

Our first design was complicated by the fact that it was impractical to get bare laser diodes. They only came attached to heat sinks. This led to the design of the first package which incorporated a deep well to accommodate the heat sink submount. Another early design was for 1550 nm DFB lasers in a package that was to operate at a speed of 2-3 GHz.

We found that the heaters, designed initially for attachment of metallized fibers to the silicon substrate, worked so well that we began designing heaters on the silicon for the attachment of optical devices, such as lasers and semiconductor optical amplifiers. We developed a very simple, versatile heater, which allowed quick evaluation of a wide range of semiconductor optical devices produced in house. This can be described as a "chip on a post".

This evolved into the design of a microbench which incorporated on-board heaters for the semiconductor amplifier and dual fiber pigtails. What follows is a more detailed description of the design of these various benches.

4.2 Design elements common to most heaters

The substrate is standard single crystal silicon. (see Fig. 3) To attach a fiber to the microbench we pattern two heating elements made of poly-silicon which are connected to gold bonding pads for electrical contact. The poly-silicon layer of 0.5 to 1 micron thickness is doped appropriately to become a controlled resistance structure. Resistivities of 10-100 Ohms-cm are typical. In the center of each heater we pattern a gold pad on a layer of silicon dioxide. This gold pad provides the solder attachment base while the silicon dioxide electrically isolates the gold pad from the poly-silicon heater. Metallized fibers can be attached with solder paste, wire, or preforms.

On some designs we utilize standard silicon etching techniques with a potassium hydroxide solution to etch deep wells in the silicon substrate. These wells can be as deep as 200 microns with a tolerance of less than +/- 5 micron. This etch technique is compatible with v-groove formation. This ability to etch wells, and by a similar process create plateaus, with tight dimensional tolerance, has proven to be crucial to the realization of the full potential of these devices, as will be discussed later in this paper.

Additional gold bonding surfaces, with appropriate adhesion layers of chrome/gold or titanium/platinum/gold, are usually added for attachment of additional devices, such as a thermister. These devices may be attached by means of standard solder techniques, using higher temperature solder than is used for laser diode and fiber attachment. The gold pads also provide contact points for wire bonds.

Typically one amp of current is flowed for 0.5 second to attach fibers. Device attachment typically requires 0.2 amps for a few seconds.

4.3 Design elements of specific package designs.

4.3.1 "Femto" package

The simplest, yet most versatile design is basically just a single heater on a rectangular substrate, 1 mm wide by 10 mm long. The heater is mounted to a post which fits into a holder with a TE cooler. Semiconductor devices can then be mounted active side up or down to the microbench. This assembly allows us to quickly evaluate devices fabricated in house using free-space optics. These microbenches have also been used in the construction of an extremely compact dual pigtail package in which femtosecond pulses were used to probe various semiconductor devices. (see Figure 4) The conically polished fiber pigtails were each about 4 mm in length to minimize effects on the short pulses, while maintaining stable coupling to the chip. These fibers were attached to the devices using UV curing adhesives.

4.3.2 High power 800 nm laser diodes

These laser diodes with 100 mw typical output power were pre-assembled active side up on diamond heat sinks. This necessitated the etching of a well to allow the device to be at the same height as the fiber core. (see Figs. 5 and 6) Tolerances of the submount height were loose, and hence a large gap existed under the fiber. Also, the thermal expansion of the submount created difficulties. We were able to produce useful devices, but the process was unpredictable.

4.3.3 "DFB packages"

We demonstrated that up to 65% optical coupling efficiency could be achieved with conically tapered fibers. We observed no decrease in the light coupled from an 800 nm laser diode into a single mode fiber after the solder had cooled. The process was however not highly reliable, with only a 20% success rate.

4.3.4 SOA Plateau

This is one of the most recent designs, incorporating heaters for the semiconductor optical amplifiers (SOAs) as well as for the dual conically polished fiber pigtails. (see Figure 7) Also the issue of parasitic current paths has been addressed by a more careful patterning of resistive and insulating structures. The microbench has been designed to be compatible with a hermetic DIP package. The 7-degree angled facet SOAs are attached active side down. A significant design innovation was the fabrication of a plateau for the device. The height of the plateau was controlled to a few microns. The predictable plateau height, coupled with the active side down device orientation has resulted in a predictable, repeatable gap between the fiber and the substrate. This has resulted in a small, predictable, and reproducible movement of the fiber during bonding. Most of the fiber attachment in these packages has been done with UV adhesive, due to the sensitivity of the devices to flux vapors.

We are developing techniques to allow soldering of the fibers without generation of any damaging vapors. This design should provide improved repeatability of the solder bonds.

5. FUTURE EFFORTS

Improvements in the use of the silicon microbenches will clearly have to be made before they gain acceptance by manufacturers and commercial companies. The resistance to a change in manufacturing processes, due to the amount of characterization and retooling required, is significant.

A number of improvements are being studied to increase the ease of use, repeatability and reliability of the microbenches. One step that would address all three issues and streamline the process is the patterning of gold-tin solder, with a protective gold layer on top, during the microbench fabrication. This solder has been shown to be usable without fluxes, eliminating the damaging vapors evolved by most fluxes. This will also mean fewer processing steps by eliminating tiny solder preforms or pastes applied by stencils and incur fewer environmental problems. The solder, applied during fabrication of the microbenches in the vacuum chamber, will be of carefully controlled composition and amount. This should address the issues of repeatability and reliability. However, thermal expansion issues need to be considered.

We are investigating geometries compatible with high speed applications in which on-board transmission lines will be needed to provide sufficient bandwidth for the O-E devices.

Our current research requirements are for only a small number of devices. Statistics need to be generated on a large number of identical packages.

6. SUMMARY

The design of a number of different silicon microbenches used in a range of applications has been presented. The advantages and difficulties of their use have been summarized. Continued development and characterization of advanced designs should lower the final assemblies costs, improve their repeatability and reliability, and lead to their acceptance by commercial manufacturers.

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Fig. 1. Thermistor Locations for Temperature Measurements

Fig. 2. Thermistor Temperatures, Pulsed Heater Input

Fig. 3. Typical silicon microbench features.

Fig. 4 "Femto" package.
Two 4 mm long conically tipped fibers pigtailed to a 1 mm long angled-facet SOA which is soldered to a simple microbench heater. Total package diameter is about 10 mm.

Fig. 5. Deep well microbench. Solder has been flowed on the left heater. Solder balls in place on right heater ready to be flowed.

Fig. 6. Detail of fiber with solder balls in place, ready to have current applied to heater.

Fig. 7. Solidstate Optical Amplifier package in 14 pin DIP package. "Angled plateau" style microbench with five heaters.