ELSEVIER

Materials Chemistry and Physics 56 (1998) 189–192

MATERIALS CHEMISTRY AND PHYSICS

Materials Science Communication

A simple passive-alignment packaging technique for laser diode modules

S.C. Wang [a], S. Chi [b], W.H. Cheng [c,*]

[a] Chunghwa Telecommunication Laboratories, 12, Lane 551, Min-Tsu Rd, Sec. 3, Yang-Mei, Taoyuan, Taiwan
[b] Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan
[c] Institute of Electro-Optical Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan

Received 15 January 1998; received in revised form 12 February 1998; accepted 30 March 1998

Abstract

A simple passive-alignment packaging technique has been developed for the fabrication of a laser diode connection to a singlemode fiber pigtail. The fabrication begins with a multimode fiber soldered in a U-groove with 5 μm tolerance. Then the laser chip with a junction-up die-bond is passively aligned to a multimode fiber and converted into a singlemode fiber. The tolerance as measured for the multimode fiber at 10% loss of maximum coupling from the laser diode is 11 μm. Because the tolerance of the multimode fiber from the laser chip is larger (11 μm) than that of the fiber in the U-groove (5 μm), this passive alignment is easily obtained. In contrast to other passive-alignment techniques, the advantages of this technique are that it is less sensitive to transverse misalignment and requires no complicated alignment marks. From laser to multimode fiber a coupling efficiency of greater than 80% and a bandwidth of greater than 1 GHz have been achieved. In this package, the overall coupling efficiency from laser to singlemode fiber is 16%. The resulting laser module with compact size and fewer components should make it highly suitable for use in low-cost telecommunication applications.

Keywords: Laser diodes; Packaging; Passive alignment; Telecommunications

1. Introduction

The extensive use of low-cost fiber-optic links for subscriber loop applications requires a considerable reduction of the cost of key components such as semiconductor lasers. High laser costs arise primarily from packaging the laser modules. Therefore, the development of high-yield passively aligned packages for low-cost laser diode module and transmitter applications is essential. One of the recent trends for developing a passively aligned low-cost laser diode module has been the use of silicon-platform technology, where a Si wafer acts as an optical bench [1–6]. The main features of the silicon optical bench are a V-groove for the fiber attachment and a mark area for alignment at the precision cleaved edge of the laser chip alignment. The laser diode chips are junction-down die-bonded on the patterned Si optical benches in order to control the relative height between laser and fiber. The fibers are then laid in the well-etched V-grooves to complete the pigtail process. However, because the coupling between laser diode and singlemode fiber is sensitive to transverse misalignment [6,7], it is difficult to obtain a good yield of high coupling efficiency by a passive-alignment process using singlemode fibers. Furthermore, the junction-down die-bonding process requires some unmetallized area on the junction surface for the purpose of alignment. The poor heat-dissipation properties of the unmetallized area can result in long-term reliability problems. Moreover, in such junction-down die-bonding packaging schemes, a complicated alignment mark is necessary.

In this work, we present a simple passively aligned technique for fabricating the laser-to-singlemode fiber pigtail. The laser chip was junction-up die-bonded on the Si optical bench with a multimode taper fiber in a U-groove pigtailed in advance. Because of the larger-tolerance design of the multimode fiber from the laser chip than of the fiber in the U-groove, the passive alignment between laser chip and multimode taper fiber was thus easily achieved. The light in the multimode fiber was then guided into a singlemode fiber by a converted multimode-to-singlemode fiber. In contrast to other passive-alignment techniques [1–6], no complicated alignment marks are needed in this process. This study has led to a simple design of a low-cost laser module for use in

* Corresponding author. Tel.: +886-7-525-2000; Fax: +886-7-525-4499; E-mail: whcheng@eo.nsysu.edu.tw

0254-0584/98/$ - see front matter
PII S0254-0584(98)00142-4

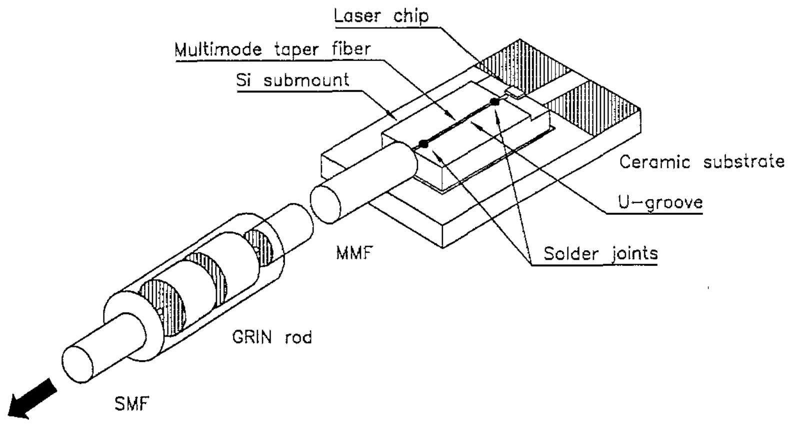

Fig. 1. Schematic layout of the passive-alignment package construction.

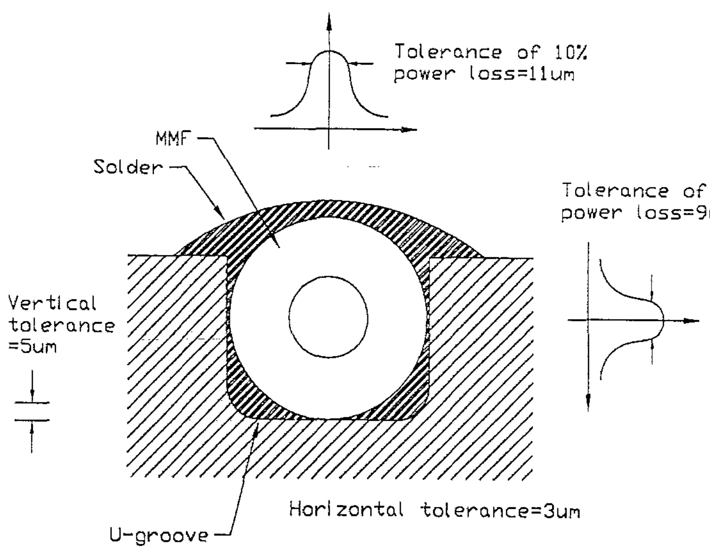

Fig. 2. Schematic diagram of the alignment tolerance between laser chip and taper fiber.

consumer telecommunication applications such as fiber to the home (FTTH).

2. Experimental

Fig. 1 shows the passive-alignment laser package construction. The package consisted of a 1.3 μm diode chip, a multimode taper fiber, a Si submount, and a ceramic substrate. Typically, the laser chip has a characteristic temperature of 90 K and a far-field angle of 20°×40° in the horizontal and vertical directions, respectively. The ceramic substrate, which was used to hold the Si submount, was given a printed gold pattern to improve solderability and to provide the laser bias circuit. In the fabrication of the Si submount, the downward step was chemically etched by a KOH bath [8] and the patterned Si wafer was then metallized on both sides with Ti/Pt/Au by a sputtering machine. The Au film thickness was about 0.4 μm. The Si submounts were cut down from the Si wafer by using a dicing saw, giving dimensions of the Si submount of 2 mm $(W)\times3.6$ mm $(L)\times0.6$ mm (H) designed to hold both the laser chip and the taper fiber. A dicing saw machine was also used to scribe a U-groove on the Si submount. The U-groove was 128 μm wide and 90 μm deep. The U-groove was used for laying down a multimode fiber with tolerances of 3 and 5 μm in the horizontal and vertical directions, respectively.

A lens tip of 65 μm curvature radius was fabricated on the fiber end using fusion methods. The curvature radius tolerance was controlled to be ±2.5 μm. This designed curvature resulted in average measured misalignment tolerances of 9 and 11 μm for a 10% loss to the maximum coupling from the laser chip on the vertical and horizontal directions, respectively, as shown in Fig. 2. The bare fiber length was less than 4 mm and the rest of the fiber was covered with a primary coating jacket of 0.9 mm Teflon.

There were two steps for the passive alignment between laser chip and singlemode fiber. The fabrication began with a multimode taper fiber soldered in a U-groove of the Si submount, which had been soldered onto a ceramic substrate in advance. The tolerances of the U-groove on the horizontal and vertical directions were 3 and 5 μm, respectively, and the maximum tolerance of the U-groove was 5 μm. Next, a laser chip was p-side-up die-bonded with its resonant cavity passively aligning to the lens tip of the taper fiber on the U-groove. Since the laser chip ridge was aligned directly to the tip of the fiber with the ridge parallel to the fiber ends, there was no need for any alignment mark. The misalignment tolerances for a 10% loss to the maximum coupling from the laser chip were 9 and 11 μm on the vertical and horizontal directions, respectively, and the maximum tolerance of misalignment of the laser chip was 11 μm. Because the tolerance of the multimode fiber from the laser chip was larger (11 μm) than that of the fiber in the U-groove (5 μm), as shown in Fig. 2, the relative position between the laser chip and multimode fiber was easily controlled through the passive-alignment process. In contrast to other passive-alignment techniques, this technique has proven to be less sensitive to transverse misalignment. In addition, no complicated alignment marks are needed in this process to prevent a bad heat-dissipation interface.

The multimode taper fiber was metallized with Ti/Pt/Au except for the lens tip. The solder for joining the Si submount onto the ceramic substrate and the fiber into the silicon submount had melting points of 330°C and 280°C, respectively. The adhesive epoxy, curing in 45 s at 175°C, for die-bonding was specially chosen to be conductive and to require no outgassing, which should provide appropriate properties for hermetic sealing. A multimode-to-singlemode converter component was used to convert the mode field distribution in the 50/125 multimode fiber layout above to that of a 10/125 singlemode fiber. This component consisted of two 0.25 pitch GRIN lens with one end connecting to the multimode fiber and the other end connecting to a singlemode fiber as shown in Fig. 1. These GRIN rods were 8° angle polished on one end and flat on the other end. In this design, the interfaces between the fiber and the GRIN rod were flat. None of the end surfaces was antireflection coated.

3. Results

To demonstrate the reproducibility of the laser-to-fiber passive-alignment technique, coupling efficiencies have been measured for more than 20 laser diode module samples. The histogram of measured coupling efficiencies for the pigtail of the laser to the multimode fiber is shown in Fig. 3. The best value for the measured coupling efficiency was 87%, and the average was 80%. This implies a very high yield of high coupling efficiency of the laser diode modules. Typically, a coupling efficiency of 20% was obtained for the multimode-to-singlemode fiber converter. The overall coupling efficiency from laser to singlemode fiber was 16%. The bandwidth of the laser module was measured to be greater than 1 GHz, which is good enough for the requirement of the OC-12 protocol. This laser-to-singlemode fiber module utilizing compact size, fewer components, and simple passive-alignment technique should make it highly suitable for use in low-cost telecommunication applications.

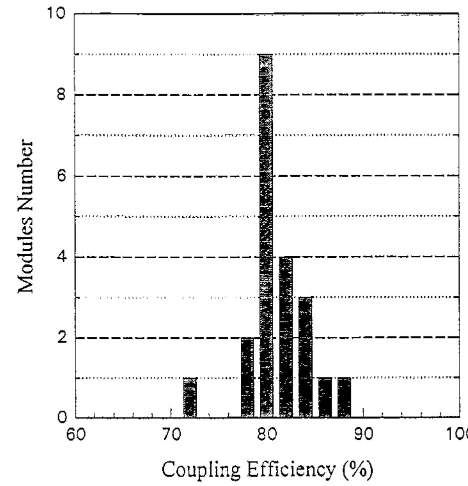

Fig. 3. Histogram of measured coupling efficiencies for laser-to-fiber modules.

4. Conclusions

A simple and efficient passive-alignment packaging technique has been presented for fabricating low-cost laser-to-singlemode fiber modules for use in telecommunication applications. By passively aligning the laser chip to the lens tip of the multimode fiber, laser modules with high yields and with high coupling efficiencies of more than 80% were obtained. This packaging technology has a great potential for hermetic sealing since all the parts are joined by non-outgassing adhesives. A more compact sized module with power monitor chip could easily be achieved with the short bare fiber length. Further improvement for converting the mode field distribution of the multimode fiber to that of a singlemode fiber is currently under investigation.

Acknowledgements

The authors would like to thank C.M. Wang and H.H. Liao of the Chunghwa Telecommunication Laboratories, Taoyuan, Taiwan, for their great help in this work.

References

[1] G. Nakagawa, K. Miura, S. Sasaki, M. Yano, Lens-coupled laser diode module integrated on silicon platform, J. Lightwave Technol. 14 (1996) 1519–1523.
[2] K. Kurate, K. Yamauchi, H. Tanaka, H. Honmou, S. Ishikawa, A surface mount single-mode laser module using passive alignment, IEEE Trans. Components Packaging Manufacturing Technol. Part B 19 (1996) 554–559.
[3] T. Hashimoto, Y. Nakasuga, Y. Yamada, H. Terui, M. Yanagisawa, K. Moriwaki, Y. Suzaki, Y. Tohmori, Y. Sakai, H. Okamoto, Hybrid

integration of spot-size converted laser diode on planar lightwave circuit platform by passive alignment technique, Photonics Technol. Lett. 8 (1996) 1504–1506.
[4] M. Fukuda, F. Ichikawa, H. Sato, Y. Hibino, K. Moriwaki, S. Tohno, T. Sugie, J. Yoshida, Plastic packaging of semiconductor laser diodes, 46th Electronic Components Technol. Conf., 1996, pp. 1101–1108.
[5] S. Sasaki, K. Tanaka, K. Miura, M. Yano, Screen printed adhesive technologies for all-silicon optical packaging, 46th Electronic Components Technol. Conf., 1996, pp. 1289–1293.
[6] J.V. Collins, I.F. Lealman, P.J. Fiddyment, A.R. Thurlow, C.W. Ford, D.C. Rogers, C.A. Jones, The packaging of large spot-size optoelectronic devices, IEEE Trans. Components Packaging Manufacturing Technol. Part B 20 (1997) 403–407.
[7] J. Yamada, Y. Murakami, J. Sakai, T. Kimura, Characteristics of a hemispherical microlens for coupling between a semiconductor laser and single-mode fiber, J. Quantum Electron. QE-16 (1980) 189–194.
[8] K.E. Petersen, Silicon as a mechanical material, Proc. IEEE 70 (1982) 420–457.