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Fabrication of a Wedge-shaped Fiber Endface by a Self-centering Technique

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Summary

We describe a technique for the fabrication of a wedge on the fiber endface, intended for high efficiency laser-to-fiber coupling. An important feature of this technique is that it is self-centering with respect to the fiber core, so that the core/clad concentricity error is uninfluential. As an application, we report experimental data on pigtailing of a 980-nm pump laser.

1 Introduction

Packaging of optical semiconductor components calls for high efficiency coupling, low back-reflections and uncritical positioning of the fiber endface in front of the chip. As the performances of the fiber-to-chip plain butt-coupling are unsatisfactory, a number of solutions have been developed, either using microoptics elements or fiber-endface shaping [1–3] into lenses or wedges.

In pigtailing signal lasers at 1300–1550 nm, one is faced with a small and asymmetric nearfield spot, much dissimilar from the standard fibers spot size and divergence. For optimum matching, one should fabricate a small-radius aspherical lens on the tip of a tapered fiber, a technology relatively critical and expensive to control, requiring, e. g., CO_2 laser ablation [4]. Good performances are obtained with spherical lenses, made by fusion of the fiber tip and much easier to fabricate, or by deposition of a high-index glass emisphere [3] and by several other approaches [3-5].

Power lasers for DFA (Doped Fiber Amplifier) pumping have less asymmetry and a broader spot size, thus pigtailing is easier with a matched fiber whose mode field radius ω_f satisfies the well-known condition [6]:

$$\omega_f = \sqrt{\omega_{lox}\omega_{loy}} \tag{1}$$

where ω_{lox}, ω_{loy} are the x- and y-half-axis of the elliptical laser spot. With such a fiber, the theoretically attainable coupling ratio η_0 for butt-coupling at a fiber-to-chip distance $z = 0$ is:

$$\eta_0 = 4\left(\omega_{lox}/\omega_{loy}\right)/\left[1+\left(\omega_{lox}/\omega_{loy}\right)\right]^2 \tag{2}$$

From (2), η_0 can be as high as 85 %, but it suddenly drops to a practical value of about 55–60 % when one works at a safe fiber-to-chip distance ($z = 5$–10 μm). Obviously, as power in such lasers is at a premium, even a small increase in coupling is of relevance.

Another point of concern in pigtailing is the minimization of power reflected back into the laser cavity. As it is well known, even small reflections can severely distort and shift the laser emission spectrum and increase power fluctuations [1, 2]. In a pump laser, this reduces the pump efficiency, and can ultimately lead to the source failure because of excessive power in the cavity [2].

A wedge-shaped fiber endface [7, 8] has been proposed for laser to fiber coupling. This is a simple, low-cost solution approximating an aspheric lens without requiring critical machining of curved surfaces on the fiber tip. Used in connection to a matched fiber, the wedge pigtail offers a working distance of 5–15 μm, markedly reduces back-reflected power and improves coupling efficiency a little bit. Instead, the improvement is substantial when using an unmatched fiber for the pigtail, as shown below.

2 Fabrication technique

The wedge is obtained by lapping the fiber tip inserted in a small capillary tube, held at a given angle with respect to the abrasive plate by a suitable fixture. To control and center the wedge with respect to the core, one should inspect the fiber tip from time to time with a microscope, and rely on a negligible concentricity error between core and clad. However, the typical concentricity error of fibers is often of the same order of magnitude of the core radius. For this reason, we have devised a method ensuring true self-centering of the wedge with respect to the core.

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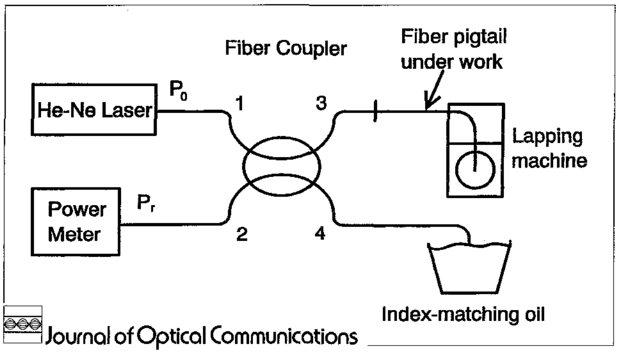

Fig. 1: Setup for real-time optical monitoring of the fiber wedge

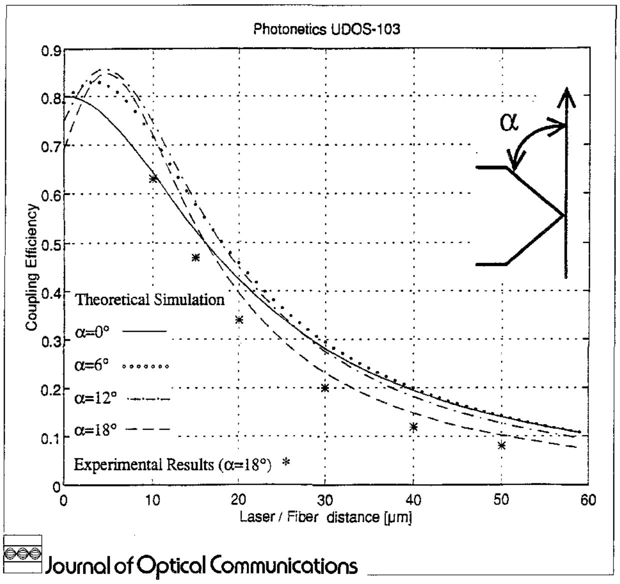

Fig. 2: Theoretical (lines) and experimental (points) coupling efficiency versus distance for butt-coupling (α = 0) and several wedges angle α; Data are for a Photonetics UDOS fiber; experimental points are for α = 18°

To this end, we metallize the fiber endface, and monitor the reflected power, as shown in Fig. 1. Here, power P_0 from a He-Ne laser is launched through a 50/50 coupler to the pigtail being worked (port 3), and light reflected back is measured by a power meter (port 4). When the edge of the lapped surface comes close to the core, a sharp reduction of reflected power P_r is observed. The exact dependence of P_r/P_0 on the distance d between the cut edge and the core center involves many parameters, and is difficult to predict theoretically. For a given fiber, a calibration curve could be obtained by observation of the edge with a metallographic microscope and a precision graticule [9], while the core position with respect to the fiber can be found by measuring the index profile.

In practice, however, the calibration curve is not required since we have found, by trying different fibers, that the optimum value to stop lapping is when P_r/P_0 drops to 50 % of its starting value, as can be expected by symmetry. In that way, the first face of the prism is easily made to reach just the core center.

To obtain the second face, the fiber is simply rotated by 180° and lapping is resumed, until a suitable fraction of the initial value of P_r/P_0 is measured. Differently from the previous case, this figure is now slighly fiber-dependent and must be found experimentally. For both fibers considered in the next paragraph the optimum value was about 1 %.

Alternatively, one can metallize again the fiber tip after polishing the first face, and then make the second face. This solution requires accurate fiber positioning on the lapping machine and results in a somewhat longer production time, but in this case the fraction of the initial value of P_r/P_0, where lapping must be stopped, is 50 %, and need not be found experimentally.

In our experiments, we preferred the first procedure, since we had to make many samples from the same fiber for pigtailing of our pump lasers. We made a few small loops (R = 1 cm) on port 1 to filter out the higher order modes. As a metal layer we used vacuum evaporated aluminum, making a deposition on a bundle of many individual fibers. To work each metallized fiber tip, we employed a dry abradant plate (SiC, 1 μm particle size) on a standard polishing machine. We preferred to fusion-splice the fiber pigtail to the 50/50 coupler, because a temporary fiber joint cannot always offer the required stability. In practice, after a brief training, the yield of the process was better than 90 %, just limited by fiber breakage during handling. Lapping a single fiber took no more than 10 minutes.

As it is customary, to improve wedge surface finish we found it useful to make a mild chemical etching or a short arc discharge, especially when using an abradant with granulometry and hardness slightly oversized.

The procedure we have described may also be extended to fabricate pyramidal [10] or double slope [8] wedges, the additional faces being lapped after a re-metallizion of the fiber tip after the first wedge.

3 Experimental results

As an example of wedge application, we report on the pigtailing of a 980 nm pump laser with two different fibers:

i) a Photonetics UDOS fiber (ω_f = 1.81 μm, the same value as the Er-doped fiber) matched to the source (SDL 6570, ω_{lox} =1.15 μm, ω_{loy} = 3 μm), and

ii) an Ensign F1060 fiber with mode field diameter (ω_f = 3.6 μm) intermediate between the UDOS and the standard SM-R fiber (ω_f = 4.5 μm).

For both fibers we made different samples to find the optimum wedge angle α.

The results for the matched fiber are shown in Fig. 3, where butt-coupling is compared to wedges with different α in terms of coupling efficiency and fiber-to-chip distance. The theoretical curves have been calculated following the guidelines of [8]. As it can be seen, the dependence on α is not critical and a 6°–18° angle is a good choice; the improvement in efficiency is only a modest one, however the distance for maximum efficiency is moved from zero to about 5 μm. Experimental points in Fig. 3 are for α = 18° and were obtained with a single-layer anti-reflection coating deposed on the wedge.

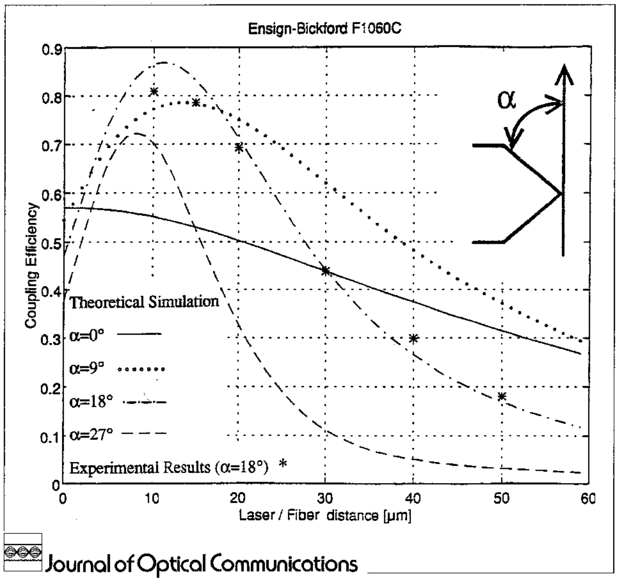

Fig. 3: Theoretical (lines) and experimental (points) coupling efficiency versus distance for butt-coupling (α = 0) and several wedges angle α; data are for an unmatched Ensign F 1060C fiber; experimental points are for α = 18°

Though we were unable to measure accurately distances less than 10 µm, a maximum of the coupling efficiency (η = 85 %) versus distance was indeed recorded for z < 10 µm.

On the other hand, the results of Fig. 3 for the unmatched fiber show a significant improvement of efficiency with the wedge with respect to butt-coupling. Here, the peak theoretical efficiency η = 85 % is reached at the optimum angle α = 18°, and in the measurements on anti-reflection coated fibers we were able to obtain η = 80 % at the increased working distance of 10 µm.

These results enlight the possibility of using an unmatched fiber to make both the pigtail of the pump laser and the WDM coupler for the fiber amplifier. If such fiber has a mode field diameter intermediate between that of the doped fiber and that of the SM-R fiber (as it is the case with the Ensign F1060C), it offers an easy way to reduce the loss at the joint between the amplifier and the optical network.

Last, we report about back-reflections of the different pigtails. Fig. 4 shows the wavelength spectrum of the pump laser for the butt-coupled fiber (dotted line) and the wedge-coupled fiber (full-line), both with anti-reflection coating. The first exhibits a peak power reduction and a second lobe, while in the second the spectrum is virtually unaffected and coincident to that specified by the supplier.

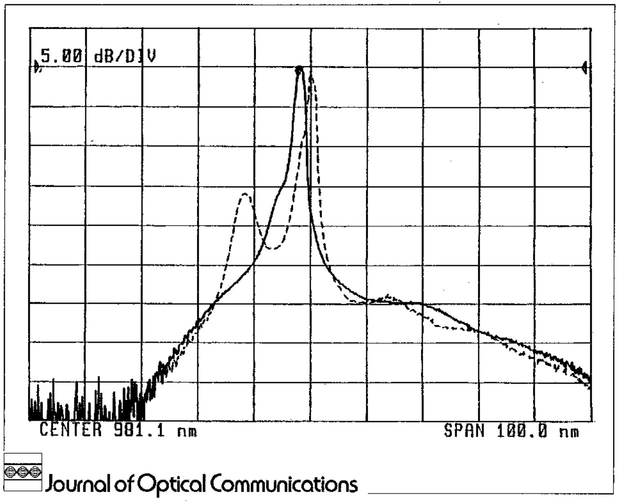

Fig. 4: Pump laser wavelength spectrum for wedge-coupling (full line) and butt-coupling (dotted line)

In conclusion, we have described a self-centering technique for wedge fabrication on fiber pigtails by lapping. The wedge pigtail improve coupling efficiency appreciably, in particular for unmatched fibers, thus relaxing the requirements on fibers for pigtails.

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