Innovative Micro-system for Pigtailing Photonic Chips

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Proper fixation of an optical fiber suffers from mechanical shifts caused by post-weld-shifts and post-relieve-shifts, which drastically affect the packaging yield during the assembly process of opto-electronic devices. The essence of the innovative fiber support design is the integration of laser assisted micro scale deformation based on contraction techniques. Herewith we obtain adequate correction of the pre-aligned fiber tip in both lateral and transversal directions. Proof-of-principle experiments successfully demonstrate accurate sub-micrometer manipulation in the range from 0 to 20 µm.

Motivation

This work arises from the need of pigtailing sample based new prototype photonic chips, which require a single mode in- and output fiber. Hence, the devices can be implemented in system related research areas within the COBRA research Institute.

Introduction

The alignment requirements for lensed fiber tips related to InP-based waveguides are typically in the sub-micrometer range. This requirement can be accomplished using commercially available manipulation systems. However, fixation of the optimum position is a much bigger challenge. Two problems can cause degradation of the aligned positions:

1) When laser welding is used to fix the aligned positions, the metal parts fuse together upon solidification to form a weld joint. However, shrinkage forces develop during this solidification. Consequently, the shrinkage forces produce misalignment, known as the post-weld-shift (PWS).
2) When the tools necessary for the alignment of the components are removed, the internal stresses between the aligned components are relieved resulting in deviations of the positions. We will refer this as the post-relieve-shift (PRS).

During the last decade, different kinds of fiber-clip designs were invented for applications in butterfly-types packages [1]. In all designs, both PWS and PRS are compensated as much as possible using laser hammering techniques. With this technique, re-adjusting of already welded parts is executed by repeatedly welding the parts again using asymmetric laser pulses. Current production figures, such as the yield, are low, but exact numbers are kept a secret because 60 – 80 % of the costs of commercially available optical devices are determined by yield and packaging costs.

Instead of laser hammering techniques, we use laser contraction techniques. This technology provides us a well-controlled step-by-step alignment approach and we have demonstrated applications for fiber array configurations in previous work [2]. In this work, we demonstrate a design for single fiber configurations and first results are reported.

Laser contraction technology

The alignment of the fiber tip is based on introducing local compressive plastic strain in the material of the fiber-support. The local strain is generated by irradiation certain parts of the fiber-support at lower output energies of a Nd:YAG laser welder. Masubuchi [3] describes in detail the transient thermal stresses of a bead-on-plate weld, which is produced by moving a welding arc. Similar stresses are produced when a steady laser beam produces a circular weld pool locally. In brief, assume that a metal sheet, as sketched in figure 1 (a), is part of the fiber support. Both in-plane stress distributions (σ_x) and (σ_y) are equal to (σ) and the initial stress in the sheet is considered to be zero. The tensile and compressive stresses are defined as presented in figure 1 (a). In figure 1 (b) a laser pulse is illustrated, which heats up the material locally and causes the local temperature to reach the melting point temperature of 1400 °C of the used material Invar. The molten metal will not support a load and therefore the thermal stresses in the center of the molted metal are close to zero. The thermal expansion of the heated area is obstructed by the surrounding non-heated material, whereas the yield strength decreases rapidly above 300 ºC. This results in a situation whereby the thermal stresses are as high as the yield stresses at the corresponding temperature profiles, symmetrically around the center of the heated area. Consequently, plastic material deformation occurs and the stresses generated in this region become compressive. The compressive stresses are in balance with tensile stresses in the regions further away from the heated center, as sketched in fig 1 (b). After the heated part of the material has cooled down to room temperature, contraction arises from the plastic deformation, which causes tensile stresses in regions at and near the center of the heated area of the metal sheet as illustrated in figure 1 (c). The residual tensile stress generates local compressive plastic strain. In figure 2 a real-time measurement of this process is shown. During the laser pulse duration of 5 ms, we measured an expansion in a metal sheet of 5 µm. Following this, after cooling down to room temperature, the net displacement ΔL in this experiment is 3 µm compared with the initial position. The displacement achieved by one laser pulse is in the order of 0.1 µm to 5 µm depending on the laser energy.

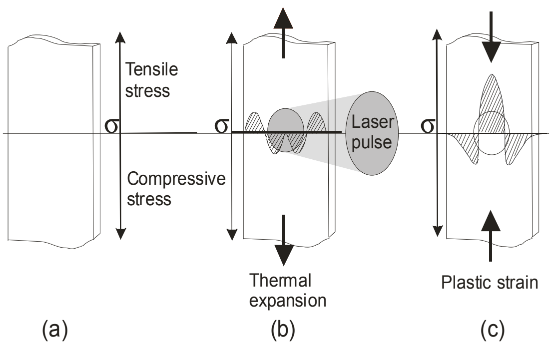

Fig. 1. Principle of laser contraction: (a) the initial stress (σ) in a metal sheet is assumed to be zero. (b) Heating up the metal beam locally. Thermal expansion occurs, resulting in plastic deformation. The stress in the center becomes compressive. (c) Contraction arises from the plastic deformation of the metal sheet after the heated zone has been cooled to room temperature. The nature of the stress in the center is tensile, generating plastic strain.

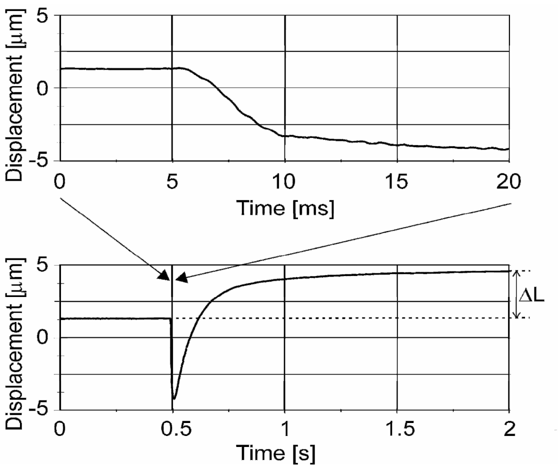

Fig. 2 Measured dynamic response of a metal sheet, which is sketched in figure 1. Upper graph: first expansion of 5 µm is measured during the laser pulse duration of 5 ms. During the cooling down period (lower graph), shrinkage in the metal sheet is measured which results in a net displacement ΔL of 3 µm.

Fiber-support design

The mechanical micro-system is shown in figure 3 and consists basically of three elements: (1) a fiber ferrule including the fiber, (2) a solid sub-support and (3) two tuning frames, already mounted at an angle of 90° related to each other to the fiber ferrule. The fiber ferrule (1) and tuning frames (3) combination is welded to the solid sub-support (2) at positions (P) and (P'), whereby the back part position (P') is not visible in figure 3. The two mounting positions P and P' act as a pivot point of the fiber ferrule whereby a predictable two-dimensional fine-tune mechanism of the fiber tip can be realized. This can be performed by using laser-induced contraction techniques executed on both tuning frames (3). The definition of the coordinate system and the displacement of the fiber tip as function of a certain heated position at the tuning frames are given in figure 4.

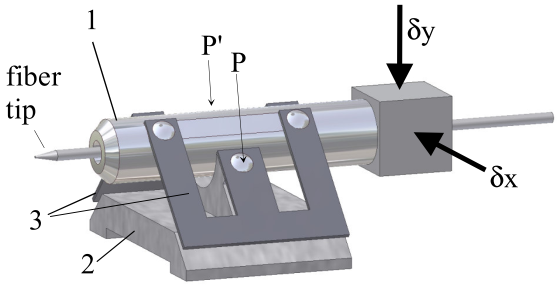

Fig. 3 Schematic presentation of the fiber support micro-system. (1) fiber ferrule including fiber, (2) solid sub-support, and (3) two tuning frames to fine-tune the fiber tip around the pivot point, which is created by points (P) and (P').

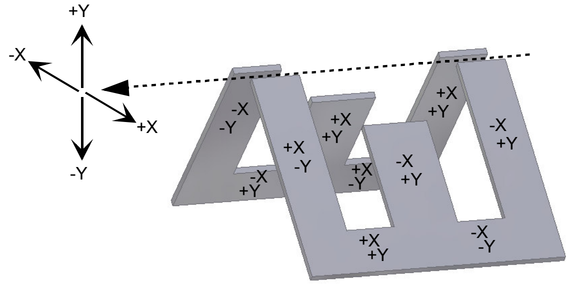

Fig. 4 The displacement of the fiber tip +X, -X, +Y, and -Y as function of the heated positions of the tuning frame.

Experimental Set-up

The set-up is shown in figure 5. The fiber ferrule is aligned to the optimum position using pneumatic tweezers (I), which are connected to a 3-axes piezo-electric manipulation system (II). The position of the fiber ferrule (I) is measured continuously in the linear δx and δy directions, located at the opposite position of the fiber tip as shown in figure 3, using a non-contact displacement measuring system based on inductive technology (III). The laser welder is a 100 W Nd:YAG laser with a pulse width of 5 ms. The laser is provided with an energy share module, which is connected to two 600 μm step-index optical fibers. These fibers deliver the energy to two focussing heads (VI) and (V) with a focus length of 100 mm. The focussing heads are positioned 90° related to each other. The beam pulse energy for welding the fiber ferrule and tuning frame combination at position (P) and (P') is 5 J for each laser head. Reduced energy in the range of 0.5 J – 4 J is used for the fine tuning process. A microscope (VI) is necessary for the visual course aligning of the fiber tip related to the optical waveguide.

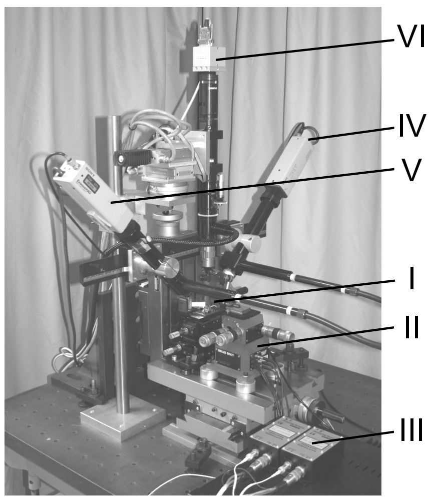

Fig.5 Photograph of the set-up.

Experimental work and results

Five dummy modules are fabricated to investigate the PWS and PRS, the range of manipulation, the step-size, and to verify the direction of fiber ferrule manipulation as a function of the heated position at the tuning frames of the micro-system. The magnitude of the PWS is in the order of 5 μm while the contribution of the PRS is somewhat lower. The range that can be adjusted is 20 μm approximately and sufficient to compensate for the PWS and PRS. By reducing the laser energy, step sizes of 0.1 μm are measured. In general, we observed the trend as described in figure 4. With the last module we manipulated the fiber ferrule back to the initial position experimentally. This procedure is visualized in figure 6. The shift of the fiber ferrule caused by PWS is 0.1 μm and 5.2 μm in the lateral X and transversal Y direction respectively. After disconnecting the pneumatic tweezers, we measured an additional shift of 1.4 μm and 2 μm in the X- and Y-direction. After seven adjustment laser shots, the fiber ferrule is manipulated back to the initial position. This concept will be elaborated as sketched in figure 7. With this concept, two lensed single mode fibers can be pigtailed to photonic chips.

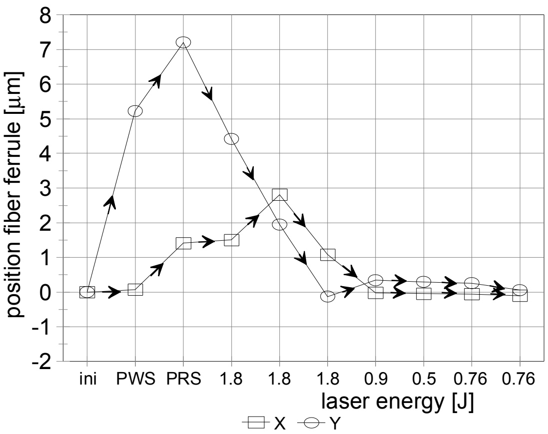

Fig. 6. Pigtail process executed at a prototype micro-system. The shifts as a result of PWS and PRS are fully compensated.

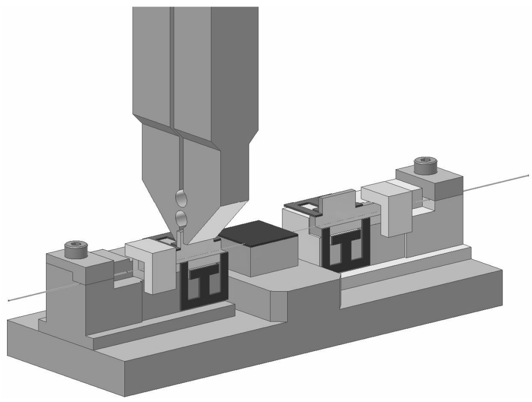

Fig. 7. An artist's impression of the implementation of two micro-systems in one device needed for an optical in- and output fiber.

Conclusions

We demonstrated a micro-system for the aligning, fixation, and re-manipulation of a fiber to compensate for the PWS and PRS during the pigtailing procedure.

Acknowledgement

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References

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