Laser Supported Actuators for Fibre Array to Chip Coupling

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Abstract. *To achieve a good coupling efficiency between a lensed fibre array and InP – based waveguides, fibre array alignment and fixation with nanometer scale accuracy is required. Laser supported actuation proves to be a promising technology for the realization of this goal. In this paper some fundamental issues about physics of laser-supported actuation are presented. A number of different parameters of actuators were investigated. The objective of our work was to gain knowledge about the influence of actuators geometry and laser beam properties on the performance of the actuators.*

Introduction

The joining method for semiconductor lasers or other optoelectronic packages by using the laser welding technique offers a number of significant advantages. It provides strong joining strength, and, therefore, the packaging has good long-term stability. It also provides high-speed and high-volume production, and, hence, the packaging has potential low cost [1], [2]. However, during the laser welding process rapid cooling of the solid phase and the associated material shrinkage often cause a post-weld shift (PWS). On a typical single-mode fibre application, if the PWS induced by the joining process is a few micrometers, up to a 50% loss in coupled power will occur, resulting in performance degradation of the packages. Therefore, the main objective of the laser welding process for the optoelectronic packages is minimizing the PWS and following laser supported fine-tuning. That's why it is very important to understand better the nature of PWS and laser – supported fine adjustment.

Experimental set up

When a laser beam heats up a spot with a radius of few micrometers of the actuator's material, residual stress will occur. The residual stress will cause deformation in the material. This deformation can be used to actuate the device on a sub-micrometer scale.
To quantify the displacement, introduced by the laser spots on the actuator, a parallelogram based measurement device with one degree of freedom was developed as presented in Figure 1.The conventional parallelograms have the disadvantage that beside the displacement in the working direction of the actuator they also cause a small displacement in direction perpendicular to the working direction of the actuator For these reasons we selected a design with a double parallelogram, which compensates for the unwanted displacement.
By using the laser welder shown on Figure 2 we were able to control precisely the laser beam spot size, pulse duration and, by changing the voltage of the welder, also the beam energy.

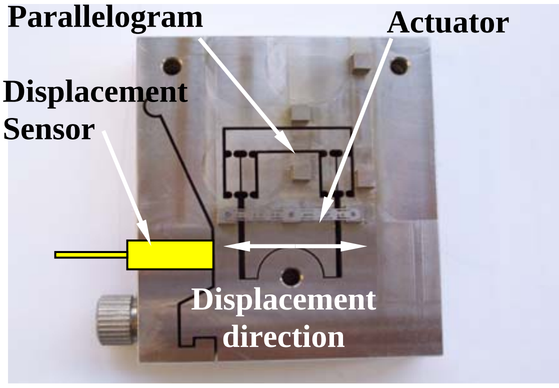
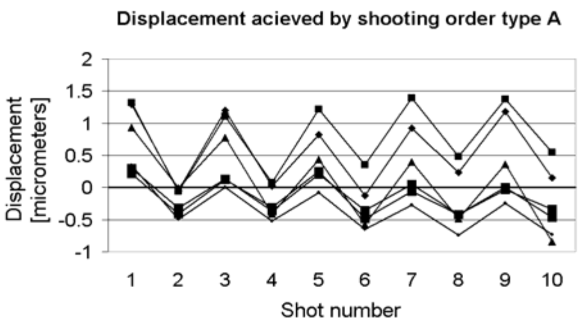


Figure1. Parallelogram base and actuator.

Figure 2. Experimental set up



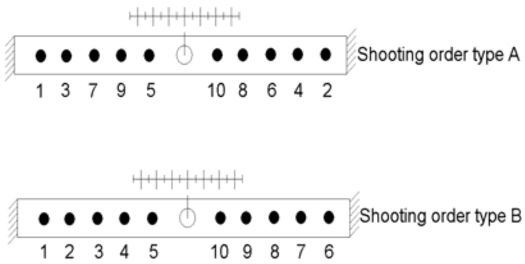


Figure 3 The shooting orders

Figure 4 Displacement achieved by shooting order type A

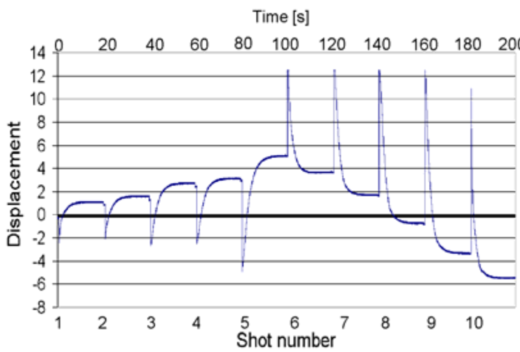


Figure 5 The displacement achieved by shooting order type B

The actuators used in our experiments were made of stainless steel strips with a length of 30 mm and cross section of 0.2mm x 1.5mm. The actuators were welded in both ends to the base, while the central spots of the actuators were fixed to the parallelogram's bench. (See fig.1) By shooting at the actuators we were actually moving the parallelogram's bench. A capacitive censor measured the displacement of the bench. The measurement resolution was 0.25 µm. The shooting orders are presented on Figure 3.The data achieved by shooting order type A represents better the step sizes (See Figure 4), whereas the data achieved by shooting order type B represents better the displacement range achieved by the actuator (See Figure 5). Figure 5 also presents the dynamical behavior of the actuators during the thermal cycle. The actuator expands very rapidly during the heating. During the cooling the actuator shrinks. Due to the residuals occurred during the thermal cycle the overall shrinkage becomes larger than the thermal expansion.

Experimental results

The conducted experiments have two main goals. The first goal was to find out the influence of thermal treatment of the material on the actuator's behavior. The second goal of our experiments was to establish how the laser beam properties affect the actuator's behavior. The results of all experiments are listed in Table 1.

	Experiment 1 Material heat treatment		**Experiment 2** Influence of laser energy		**Experiment3** Influence of pulse duration		**Experiment 4** Influence of the spot size		
Shot no.	Not annealed Standard Deviation	Annealed Material Standard Deviation	Laser beam Energy	Step size	Time	Step size	Spot radius	Step size ED variable	Step size ED constant
	[μm]	[μm]	[J]	[μm]	[ms]	[μm]	[μm]	[μm]	[μm]
1	0.176	0.052	1.4	0.104	1	1.062	315	0.28	0.88
2	0.0245	0.067	1.6	0.39	3	0.701	423	0.115	1.64
3	0.183	0.06	1.8	0.299	5	1.47	530	0.103	2.01
4	0.22	0.089	2.03	0.44	7	0.8	640	-0.328	5.41
5	0.319	0.144	2.25	0.73	9	2.12	775	-0.125	-
6	0.381	0.119	2.45	1.14	11	1.45	315	0.59	0.61
7	0.406	0.134	2.7	0.88	13	1.86	423	0.434	0.22
8	0.408	0.148	2.94	0.51	15	2.36	530	-0.165	1
9	0.437	0.109	3.18	1.07	17	2.54	640	-0.22	3.22
10	0.585	0.165	3.36	0.95	19	2.2	775	-0.137	6.16
Σ	3.139	1.087	-	6.51	-	16.53		0.444	21.5
	Shooting order type A see Fig.3		Shooting order type B see Fig 3		Shooting order type B see Fig.3		Shooting order type B see Fig.3		

Table 1 The experimental results

Experiment 1: The aim of the first experiment was to define the importance of heat treatment of the material. Therefore, 6 samples with identical geometrical dimensions were selected. In three of the samples the post manufacturing stress was retained. The rest of the actuators were heated up to 860 °C for 5 hours, then they were cooled down to room temperature at a speed of 30 °C per hour. Thus the material of these actuators can be considered stress-free. 10 shots were performed according to shooting order type A. See Fig.3. Based on the measured displacements of the parallelogram's face, we have calculated the standard deviation. See Table 1.The standard deviation represents the spreading between the positions achieved by the actuators after each consecutive shot. Table 1 shows that the annealed actuators have a smaller standard deviation than the actuators, which are not annealed. As a result, we can conclude that the performance of annealed actuators can be easily foreseen.

Experiment 2: The aim of the second experiment was to establish the impact of laser beam energy on the performance of the actuators. The actuators used in this experiment have the same geometry as the actuators used in the previous experiment. By changing the input voltage of the laser welder we were able to control precisely the energy of the laser beam. The other parameter of the beam, i.e. the pulse duration and the size of the spot in which the beam is focused, was kept constant. 10 shots were performed according to shooting order type B. See fig. 3. The used energies in [J] and achieved step sizes are listed in Table 1. There is some nonuniformity in the results, which can be caused by some local non-predicted stresses in the material. However, as a whole we observed that by increasing the energy of the laser beam the step sizes increase as well.

Experiment 3: The aim of the third experiment was to establish the impact of laser beam pulse duration on the performance of the actuators. In this experiment the energy and the size of the laser heated spot were constant. 10 shots were performed according to shooting order type B. The used pulse durations and achieved step sizes are listed in Table 1. Unfortunately, there are again some fluctuations of the results, caused by unpredicted stresses. However, we observed that, generally, with the increase of the duration of the laser pulse the step size increases too.

Experiment 4: The change in the laser beam spot size has direct influence on the energy density (ED). The increase of the spot size reduces the ED and, respectively, the temperature in the heated spot. Therefore, the forth experiment was divided in two parts.

The aim of the first part of the experiment was to isolate only the influence of spot size. The different energies of the laser beam were used in order to keep the ED constant. Pulse duration was constant too. There were performed 10 shots according to shooting order type B. See fig.3 Table 1 lists the radii of the heated spots as well as related step sizes. We observed that when the heated spot becomes larger and the temperature in the spot is constant, the step sizes performed by the actuator can increase.

The aim of the second part of the experiment was to examine the behavior of the actuators if only the spot size is changed while the laser beam energy and pulse duration are constant. In this case the temperature of the material in the heated spot decreases when the spot size increases. Here increasing the spot is actually defocusing of the laser beam. We performed 10 shots according to shooting order type B. The spot size radii used in the second part of the experiment were the same as those used in the first part of the experiment. This time we observed that with increasing the spot size the steps performed by the actuator decrease. Table 1 lists the radii of the heated spots as well as related step sizes. The negative values indicate that the actuators do not shrink any more but actually expand. This "relaxation" effect can be useful in case when the maximal range of the actuator is reached and we are not able to move back in other way.

Conclusions

The performance of the examined actuators is much more uniform if all post-manufacturing stresses are reduced by annealing. By increasing the pulse duration, laser beam energy and spot size, the step sizes performed by the actuators also increase. In case when the spot size increases but the energy density is not taken into account, the steps performed by the actuator decrease. Under some circumstances the actuator can expand.

References

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