Laser soldering of piezoelectric actuator with minimal thermal impact

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Abstract

Mechanical and electrical connecting of piezoelectric actuator is often done using conductive glue. Its advantage is not to heat the piezoelectric actuator during connection. But there are many disadvantages to gluing; the main one is curing time. Welding is another alternative, but when done in an oven, the temperature needed for this operation might destroy the heat sensitive actuator.

The method described in this paper is laser soldering of piezoelectric actuator. The piezo actuator is mechanically and electrically connected to an alumina substrate by the use of tin solder heated by the mean of a laser diode. The advantage of the laser diode is its ability to selectively heat needed areas. Moreover, it is possible to control the energy brought to the system during the soldering process, thus reducing thermal impact on the piezoelectric actuator. Finally, the temperature can be monitored during the soldering process, allowing to control if the piezoelectric actuator was exposed to high temperature.

Keywords: Laser soldering, piezoelectric actuator connecting, thermal control, PZT depolarization.

1. Introduction

The goal of this paper is to describe an attachment method for piezoelectric actuators. First, a description of the problem is done in section 1. The proposed case study is detailed in section 2, describing two different piezoelectric actuators to be connected. Section 3 summarizes several heating methods used for soldering. Then section 4 is a description of the setup used for soldering of the piezoelectric actuator. Section 5 presents measurement methods, and the results. Finally, conclusions are drawn in section 6.

Depolarization of piezoelectric actuator happens when heated [1]. That is why soldering of such an actuator on a substrate is not often used. After soldering, repolarization is needed, which is not always possible, for example if the piezoelectric actuator is part of an electrically sensitive device. Moreover, repolarization is an operation that takes time.

The proposed method is to use a laser diode for the soldering operation. Such equipment is already used for packaging of heat sensitive microsystems, or for curing of epoxy glue. A pyrometer is used to monitor the temperature during the soldering process. This allows determining if the device was heated over a given limit. The combination of focused heating and temperature monitoring increases the yield of this sensitive assembly operation.

2. Case study

The chosen case study deals with the soldering of piezoelectric actuators on ceramic substrates (alumina, or LTCC). The aim is to integrate such actuators in an LTCC device, a micro electrovalve for example [2]. For our tests, alumina substrates were designed, with screen-printed metallic pads, allowing mechanical and electrical connection of the actuators.

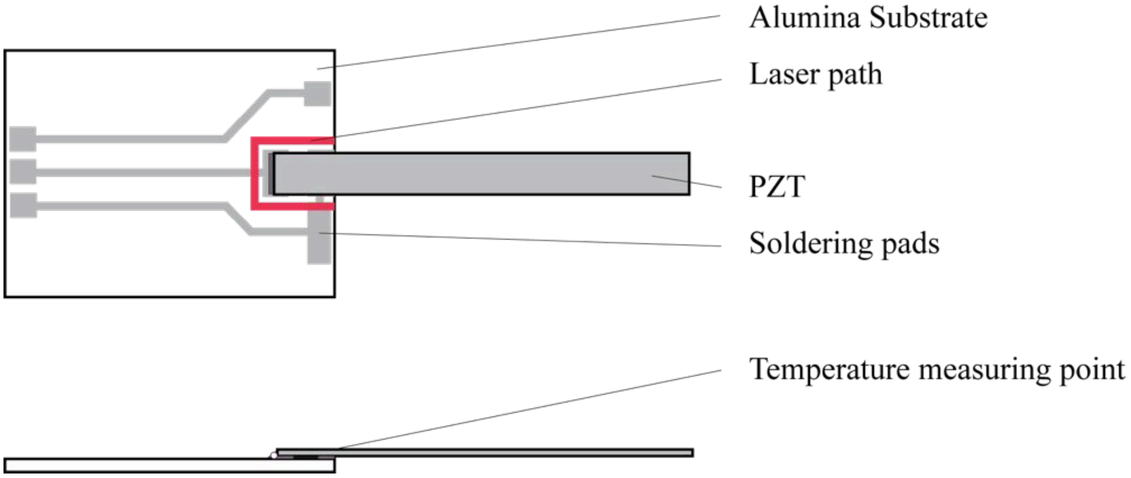


Figure 1 - General view of the assembly

2.1. Piezo electric actuators

Two different types of piezoelectric actuators were chosen. Both have advantages and drawbacks regarding assembly. Cost is also a determining factor.

The first soldered sample is a multilayer piezoelectric actuator. The sides of this actuator are metallized. Attachment to a substrate can be done quite easily, by dispensing solder between the substrate and the metallized surfaces. The price for 200 pieces is 40 USD.

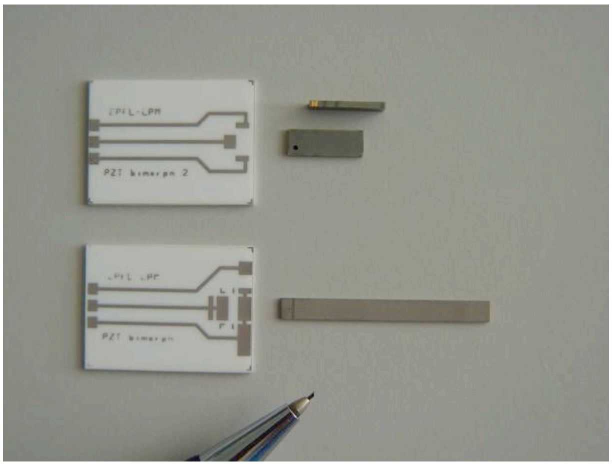


Figure 2 - PZT actuators and alumina substrates. Note metallization pads for the first PZT actuator

The second sample type is a bimorph piezoelectric actuator [5].It is more complicated to contact, as upper and lower surfaces are metallized (nickel), and the center shim (brass) also has to be electrically connected. The bottom surface is easily brazed on the alumina. This contact ensures mechanical and electrical connection at the same time. For contacting the centre shim, a fillet of Sn-Bi paste is applied, after having electrically isolated the top and bottom nickel pads at one tip of the actuator (Figure 4). The price for 200 pieces is less than 12 USD.

Both types of piezoelectric actuators were soldered using the laser diode, but only the second type was electrically and mechanically tested after soldering. All the following results have been obtained with this type of actuator, shown in figure 3.

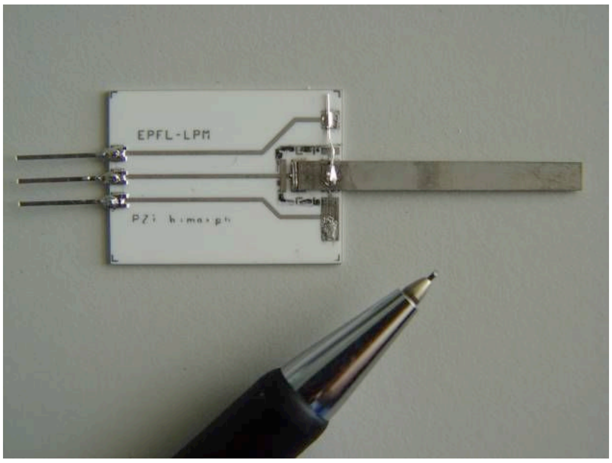


Figure 3 - PZT actuator after soldering

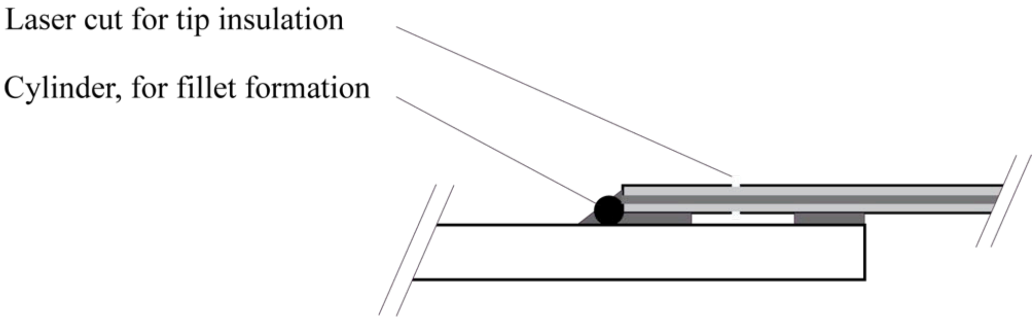


Figure 4 - Details of layers contacting

3. Comparison of soldering methods

3.1. Reflow Oven

A common soldering method is the use of a reflow oven. The main advantage is the possibility to process batches of components. Thermal inertia is quite low in comparison with heating plate or standard oven. But the main drawback is the sensitivity to radiation absorption of the surface of the component. The heating occurs through radiation, and it is difficult to ensure a repetitive and uniform heating of the components to be soldered. Dark surfaces will heat more than white ones. Moreover, as for other ovens, the whole component is heated, which might lead to depolarization.

3.2. Belt furnace

An often-used device is the belt furnace. Like for the reflow oven, the advantage is the possibility of batch processing. A temperature profile can be given and followed, but in this case also, the whole component is heated. For high melting temperature solder pastes, depolarization of the piezoelectric actuator may occur.

3.3. Heating plate

Another alternative, for small batches, is the use of a heating plate. It is often used for prototypes and soldering tests. Like for the ovens, the heating is transmitted to the whole component. For practical reasons, it is not convenient for industrialization of soldering process.

3.4. Laser diode

Finally, the solution that is proposed is the use of a laser diode. There are several advantages. It is possible to process batches of components. The heating is very focused, and the power of the diode can be controlled during the soldering process. The thermal inertia of the heating device is inexistent, which means that the only limit for temperature profile is the thermal inertia of the soldered component itself. The only heating occurs through conduction inside the component. A more detailed description of the soldering process using a laser diode is made in section 4.

4. Setup and heating method

The setup is composed of a 30W laser diode (Figure 5). The power of the laser can be adjusted continuously during the shot, between 0 and 30W. The beam of the laser is focused by a telecentric optics, the smallest diameter of spot is 0,5mm. By defocusing, a larger diameter can be achieved. The laser spot position can be controlled by a galvanometer head on a 50mm x 50mm surface. The maximum speed of the laser spot is 1 m/s. The advantage is that the power density is low, which is an advantage in our case. Another advantage is that the cost is about the half of a Nd:YAG or CO_2 laser.

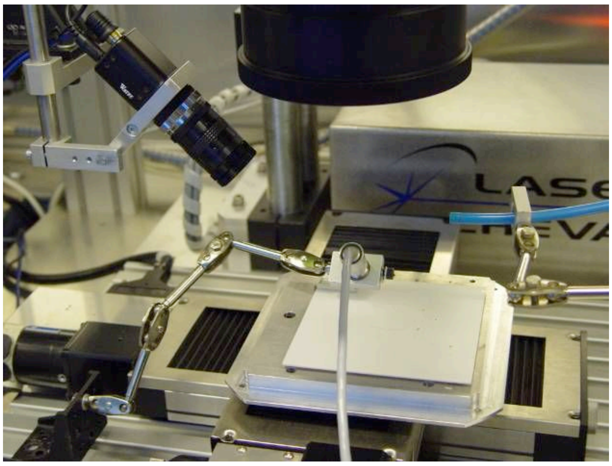


Figure 5 - Setup used for soldering. Note the galvanometer head at the top, the camera on the left, and the pyrometer, hiding the soldered device.

Temperature can be monitored by a pyrometer. This measurement allows monitoring of the process during soldering, at one point of the device to be soldered. The reading of the temperature can also be used to control the power of the laser, by using a feedback loop, but this wasn't used for this project.

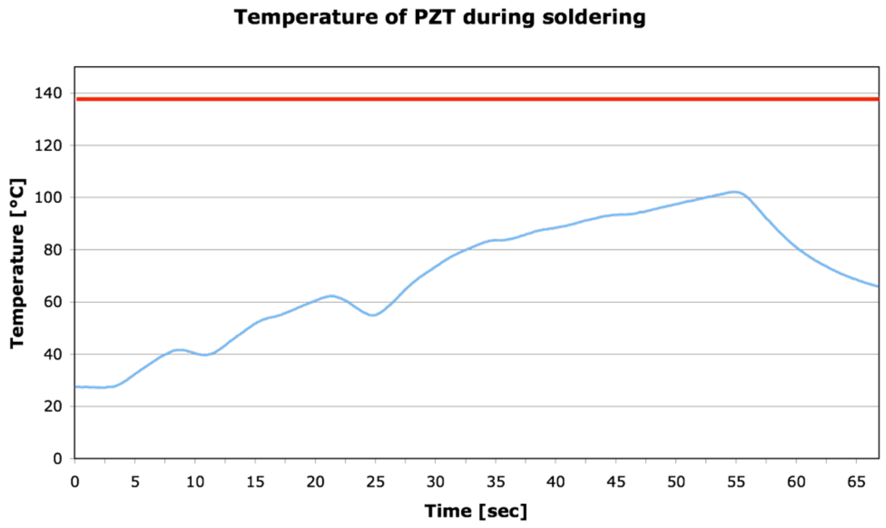
In our case, the temperature is monitored on the top of the piezoelectric actuator, at the beginning of the active zone of the actuator (Figure 1). Determination of the emissivity value of the piezoelectric actuator surface was done on a heating plate, before doing the tests with the laser.

The actuator is not heated directly by the laser spot. This is due to the fact that the soldering paste can not be heated directly by the laser, because it is hidden under the piezoelectric actuator. That is why conductive heating is used. A path is described by the laser spot, around the piezoelectric actuator (Figure 1). To increase the absorption of the laser beam by the alumina substrate, the path is covered by graphite. By heat conduction in the alumina, the solder paste is heated until melting temperature is reached.

5. Measurements and results

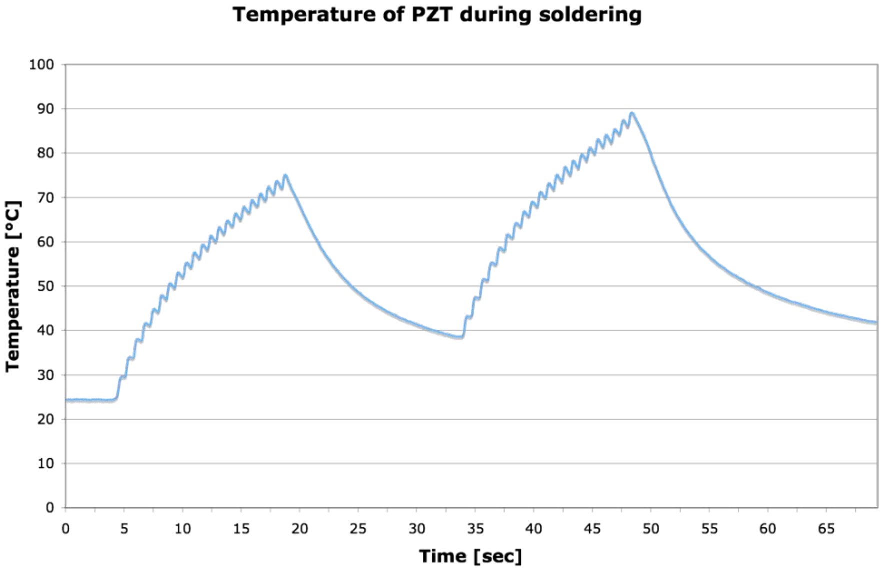
5.1. Thermal impact during soldering process

Several samples were soldered with SnBi solder paste. The melting point of such a paste is 138°C. The power of the laser diode is increased with time until the paste melts. At that point, the power of the laser is maintained for a few seconds. Finally, the power is gradually reduced. A typical temperature profile obtained at the measuring point (top of the piezoelectric actuator) is given in the graph below.



The variations in heating are due to manual adjustments during the soldering process. One can see that maximum temperature reached is about 100°C. The red horizontal line is the melting temperature of SnBi solder paste (138°C). The difference is due to the fact that the solder paste lies under the actuator, whereas the temperature measuring point is the top of the PZT.

Another typical profile temperature is obtained by reducing power during soldering process. In this case, a lower temperature was reached. This can be seen on the graph below.



In this case, a power of 15W was applied for 15 seconds twice, with a pause of 15 seconds between both shots. One can see that due to higher initial temperature, the second pulse reaches sufficient temperature, allowing melting of the solder paste. The small variations of temperature during soldering are due to the fact that the heating point moves around the actuator, whereas the position of the temperature measuring spot is fixed. When the laser spot is closer to the temperature measuring spot, the temperature increases faster.

5.2. Mechanical performances of piezoelectric actuators after soldering

Two types of measurements were done. The first one is maximum amplitude of free deflection of the tip, the second one is the force at the tip as a function of the voltage. These two measurements were done on a bench described in [3]. This bench consists of a Keyence position sensor, and a Millinewton force sensor [4]. Both devices are controlled by a Labview Virtual Instrument. The piezo electric actuator is actuated by the mean of a tension source driven by a function generator.

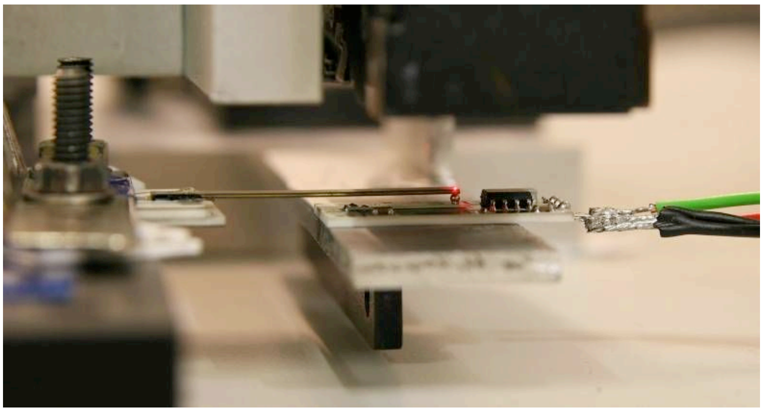


Figure 6 - PZT Actuator on the bench. Note the Millinewton sensor, and the Keyence position sensor

5.3. Maximum free amplitude

Even if is not a good indicator of mechanical behaviour of the solder joint, maximum free amplitude measurement is interesting, as it easily shows if depolarization occurred during attachment process. The first sample made on a hot plate and using SnCuAg solder paste only had a free amplitude of 70 µm. On the other hand, samples made using the laser diode and SnBi solder paste had a free amplitude close to 200 µm, which is similar to what is indicated in the datasheet [5]. Results are summarized in the table below.

Sample	Solder paste	Heating method	Maximum Temperature reached by PZT	Free deflection
01	SnCuAg 240°C	Heating plate	250°C	135 µm 178 µm after repolarization
02	SnBi 138°C	Laser diode	90 °C	214 µm
03	SnBi 138°C	Laser diode	102 °C	210 µm
04	SnBi 138°C	Laser diode	95°C	Shortcut during soldering
05	SnBi 138°C	Heating plate	250°C	175 µm

For sample 05, the PZT was heated by a heating plate for 10 minutes at 250°C. The effect of depolarization can be observed.

5.4. Force at the tip

In this case, the actuator is blocked by a MilliNewton force sensor. The deflection and the force are measured. Results are summarized in the table below:

Sample	Deflection	Blocked force
01	5.96 µm	42.3 mN
02	8.67 µm	69.5 mN
03	8.45 µm	62.9 mN
04	-	-
05	7.51 µm	53.0 mN

In this case also, depolarization is observed, for samples 01 and 05. The values are also close to the announced value [5].

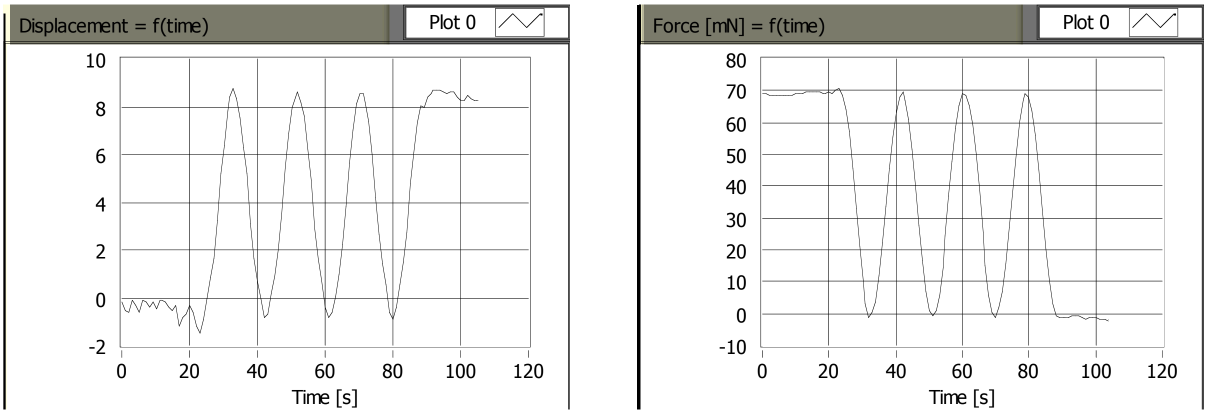
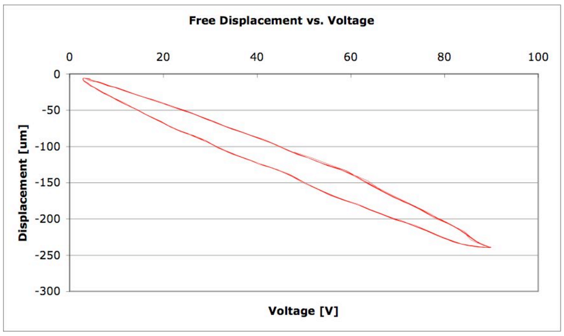
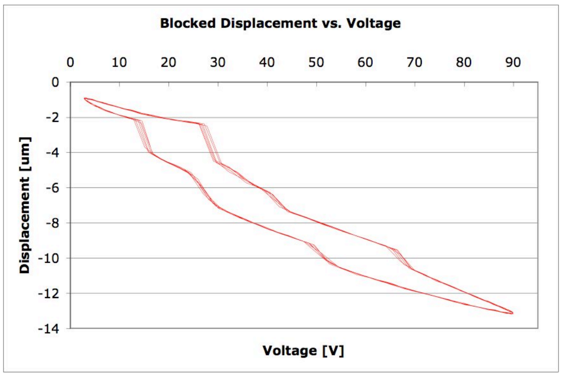


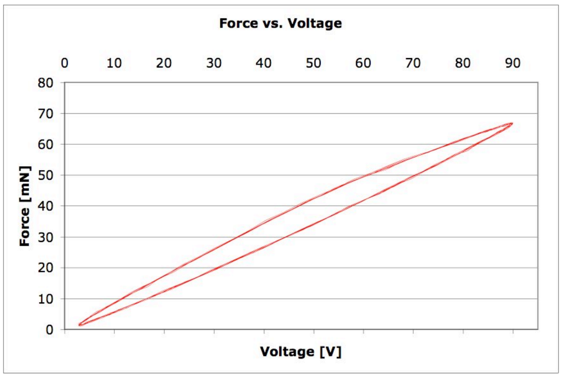
Figure 7 - Displacement and force for sample 02

5.5. Hysteresis observation

The following graphs show the hysteresis observed in both free and blocked measurements. It is difficult to know if a part of this hysteresis is due to the attachment. Nevertheless, this is similar to what is announced in [5]. Irregularities in the blocked displacement are difficult to explain. As they don’t appear in the free displacement, they might be due to the millinewton sensor.







6. Conclusion and future work

This work proposed a method allowing soldering of piezoelectric actuators without heating higher than depolarization temperature. Measurements showed that good performances were obtained with the soldered piezoelectric actuators.

In comparison with gluing, laser soldering allows a short assembly time. Moreover, electrical connection is obtained. By use of screen-printing or dispense for the solder paste, it is possible to make this process repetitive, increasing the yield of the assembly operation.

A drawback of this method is the non-uniformity of heating: due to conduction, the alumina substrate is always at higher temperature than the piezoelectric actuator. In this case, the wettability is poor on the PZT, which implies longer heating times to obtain a good solder joint.

Further tests need to be done in order to determine resistance of the solder joint to cycles. If necessary, a complementary attachment method might be needed, for example epoxy glue or clamping. Nevertheless, the proposed contacting method by soldering is applicable for batch production.

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