Characterization of Micro Resistance Welding with Electro-thermal Actuator for Micro Assembly

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ABSTRACT

Optical MEMS devices rely on the micro assembly to achieve re-positioning, such as lifted up micro mirrors and lens and micro resistance welding benefits assembly of optical components. However, the characteristics of micro resistance welding are still unknown. The purpose of this study is to characterize micro resistance welding with electro-thermal actuator for micro assembly. In order to characterize influence of operation parameters on micro resistance welding, important parameters including contact pressure, contact resistance and electrical energy are calibrated. Further, welding strength provide robust join are also measured. The idea of resistance welding is based on generated heat by ohm's law to melt material. From measured results, contact resistance decreases with increasing contact pressure due to increasing contact area. The stronger welding strength can be achieved at a smaller initial contact resistance which means that a larger clamping force could enhance the welding strength. The maximum welding strength is 74.4 μN at 2.7 Ω. Further, welding energy affects yield significantly. At high welding energy, between 1 to 10 J, the yield can reach 100 %. The energy below 0.05 J would not generate adequate heat to weld structure.

Keywords: micro resistance welding, micro assembly, thermal fusion, thermal assembly, micro welding

1. INTRODUCTION

The trend of MEMS development tends to reach various fields and different kinds of devices. Micro assembly can be helpful to integrate micro components, especially optical devices, in a micro system, such as integrated micro optical systems [1]. Various assembly methods have been proposed including micromanipulation using micro grippers or end-effectors also known as pick and place method [2], capillary forces to achieve parallel self-assembly [3-5], and plastic deformation magnetic assembly techniques [6] using external magnetic field. Amount the previous studies, one of feasible methods is thermal assembly by welding process. The advantages of thermal assembly include good mechanical strength and electrical conduction can be achieved while welding conductive materials. Also, resistance welding is a common scheme of assembly in macro scale. However, the characteristic of resistance welding in micro scale rarely discussed. In this study, resistance welding with an electro-thermal micro actuator aid to accomplish assembly Ni micro structure is experimentally investigated and characterized.

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2. DESIGN CONCEPT

Resistance welding is fusion of metals at contact surfaces by the heat generated due to the joule heating when the welding current runs through the workpieces. After pushing two workpieces together with proper contact pressure, the contact points will have high resistance when welding current is applied through contact points. Temperature may be raised to the melting temperature by joule heating. Resistance welding involves proper coordination of electrical current and mechanical pressure [7]. The amount of generated heat depends on welding time, current, and the resistance at the interface, which can be expressed as $Q=I^2RT$ where Q is heat generated, I is welding current, R is resistance at the interface or contact resistance, and T is welding time.

The concept design of micro resistance welding with electro-thermal micro actuator is shown in figure 1, which can be described in three steps: 1) Press: Actuator unit pushes welding unit 1 to contact with unit 2. 2) Hold and Weld: The electrical current passes through the contact joint to perform resistance welding. 3) Release: The actuator unit is released from the welding unit. Two-mask fabrication process with metal-based surface micromachining is adopted to fabricate the structure, as shown in Figure 2 To characterize the influence of operation parameters on micro resistance welding, important parameters including contact pressure, contact resistance and applied electrical energy are calibrated. Moreover, the mechanical strength of welded joint is measured by pulling the welded joint with a probe tip after the successful welding to evaluate the performance of micro resistance welding.

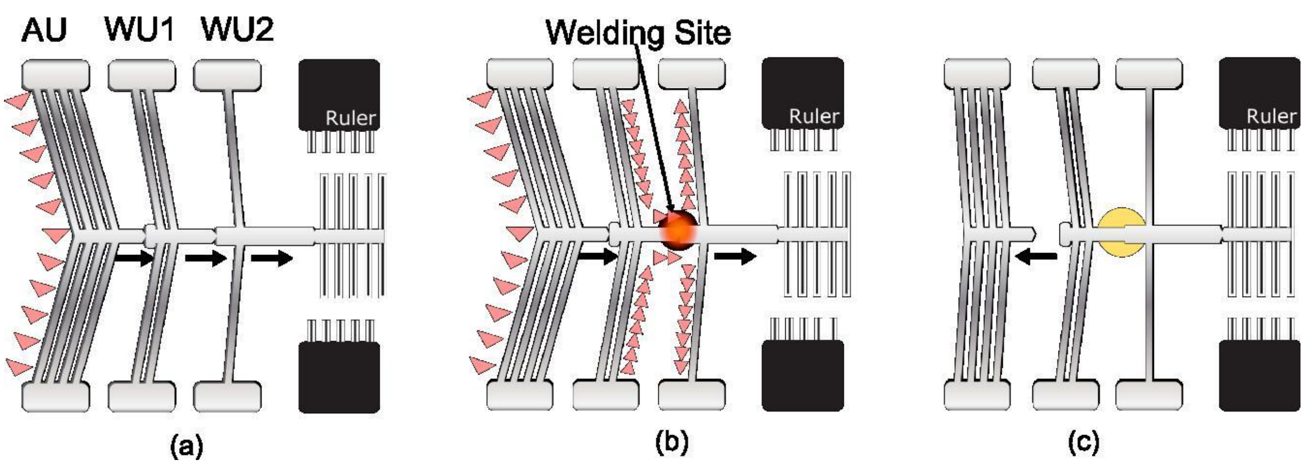


Figure 1. The schema of design concept. The structure includes actuation unit (AU), welding unit 1 (WU1) and welding unit 2 (WU2). (a) Clamp structure (press) (b) Hold contact pressure and practice welding (hold and weld) (c) Turn off electricity (release)

3. FABRICATION

The micro resistance welding structure is fabricated using metal-based surface micromachining. This fabrication process is illustrated in figure 2. First, a 500 nm wet thermal oxide thin film grown at 1050 °C in a conventional horizontal quartz furnace. The oxide layer acts as electrical isolation and sacrificial material. Then FH-6400 photoresistor is coated and patterned to act as the sacrificial layer. The Ti/Cu thin film of 20/120 nm is then deposited on the oxide layer by DC-sputter as the adhesion and seed layer for electroplating. Another 10 μm-thick photoresistor layer, AZP-4620, is patterned with the second mask. After that, nickel is electroplated to form the metal structures. The temperature of electroplating process is controlled at 50°C, and the current density is controlled at 20 mA/cm^2. Finally, the electroplated structure is released by sequentially stripping the sacrificial layer with acetone (ACE) and rinsing in isopropylalcohol (IPA) as well as deionized (DI) water. Once the Cu/Ti layer underneath the released structure is removed by immersing in a diluted CR-7T and buffered oxide etchant (BOE), the released nickel structure is ready for following resistance welding tests. The picture of fabricated structure by scanning electron microscope is shown in figure 3.

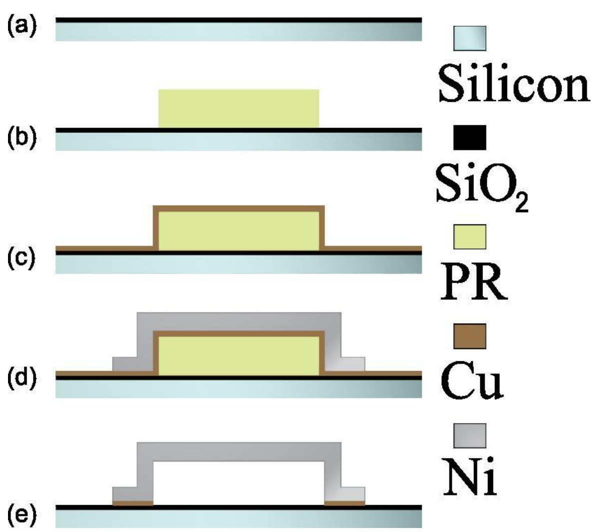


Figure 2. Fabrication process flow of micro welding structure

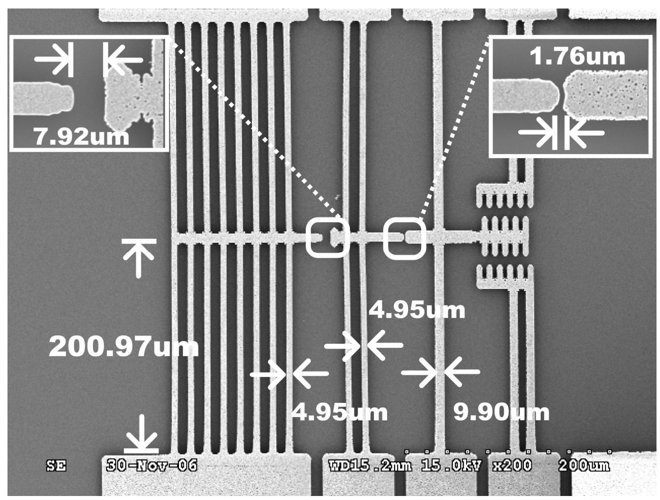


Figure 3. The SEM photos of fabricated micro welding structure before welding.

4. MEASUREMENTS

The objective of the present experiment is to investigate the characteristics of resistance welding in micro scale to provide fundamental information for this assembly technology. Here, welding current, contact resistance, and welding time are measured and recorded.

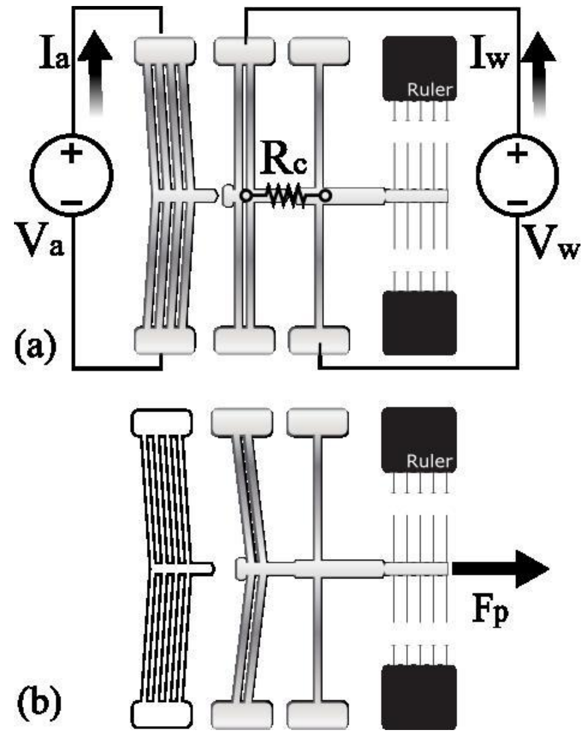


Figure 4. Schematic diagram of measuring (a) electrical characteristics and (b) welding strength.

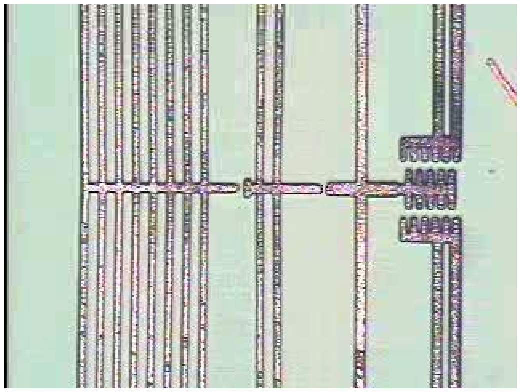
Furthermore, contact pressure would have influence on the initial contact resistance which is defined as the contact resistance at welding site before welding, namely, the resistance at welding site in first step, press. In contract to initial contact resistance, post contact resistance is defined as the resistance after welding. The initial contact resistance reflects the surface conditions at the contact interface, as well as the post contact resistance characterizes the quality of the welding. The smaller post contact resistance means that the welded join has higher electrical conductivity after welding.

As shown in figure 4(a), the electrical characteristics of the welding (V_w and I_w) would be measured as well as the parameters mentioned above. Moreover, the resistance could be calculated from the data of V_w and I_w, by ohm's law, however, which is consist of structural resistance and contact resistance at welding site, R_c. It has to subtract the structural resistance to obtain the contact resistance. The structural resistance would be calibrated before the welding.

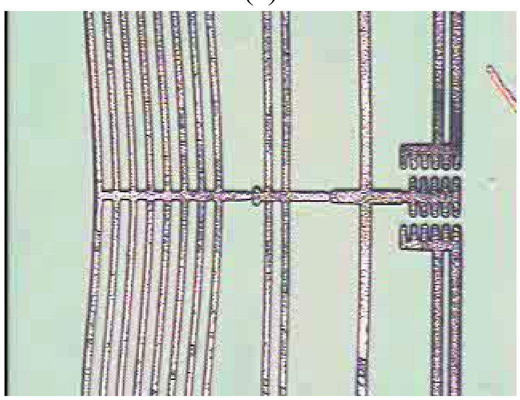
The measurement of welding strength is performed using a probe tip to pull the welded join and trying to separate the join, as show in figure 4(b). The deflection of welding unit 2 will be observed carefully. The bonding force is calculated with the measured deflection and the stiffness of welding unit 2 at the instant when the welded join is just separated. In addition, welding strength can be defined as bonding force divided by cross-sectional area of the welded join.

5. RESULTS AND DISCUSSION

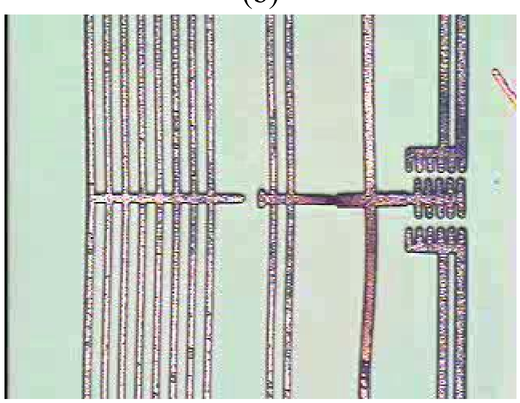
An example of successful micro resistance welding process is shown in figure 5. Figure 5(a)-(c) show a serial sequence of welding process.



(a)



(b)



(c)

Figure 5. The micro resistance welding process. (a) All parts rest at initial state. (b) Actuation unit pushes the welding unit 1 to contact with the unit 2. (c) The compression is released from the actuation unit.

Figure 5(a) is the initial state of micro structure. In figure 5(b), the actuation unit pushes the welding unit 1 to contact with unit 2. After applying proper welding energy, the material around welding point is melted to achieve assembly. Then the actuator is released, as shown in figure 5(c), to complete the micro resistance welding process.

From measured results, the clamping force exerted by the actuation unit has an obvious correlation with the contact resistance from the interface between the welding unit 1 and unit 2, as shown in figure 6. The contact resistance decreases with the increasing contact pressure, where the largest contact resistance is 3.9 ohm at 7.76 MPa and the lowest is 0.4 ohm at 73.2 MPa. Also, as shown in figure 7, stronger welding strength can be achieved at a smaller initial contact resistance. It indicates that a larger clamping force could enhance the welding strength. The welding strength can reach as large as 74.4 μN at contact resistance of 2.7 Ω and only 3.2 μN at 57.4Ω. As shown in figure 8, when welding energy below the threshold limit of 0.05 J, the welding trials all failed. For the energy between 0.05 J and 1 J, there is transition from a lower yield of 33.3 % to a higher yield of 58.3 %. At high welding energy, between 1 to 10 J, the yield can reach 100 %. In summary, the smaller contact resistance could benefit the welding strength and applied heat has a minimum requirement.

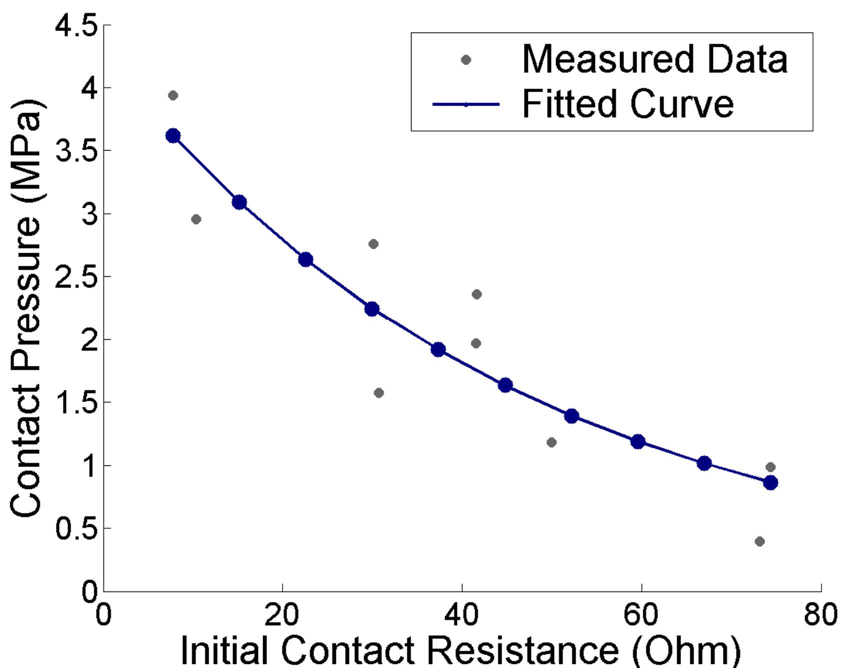


Figure 6. Contact pressures with different contact resistance

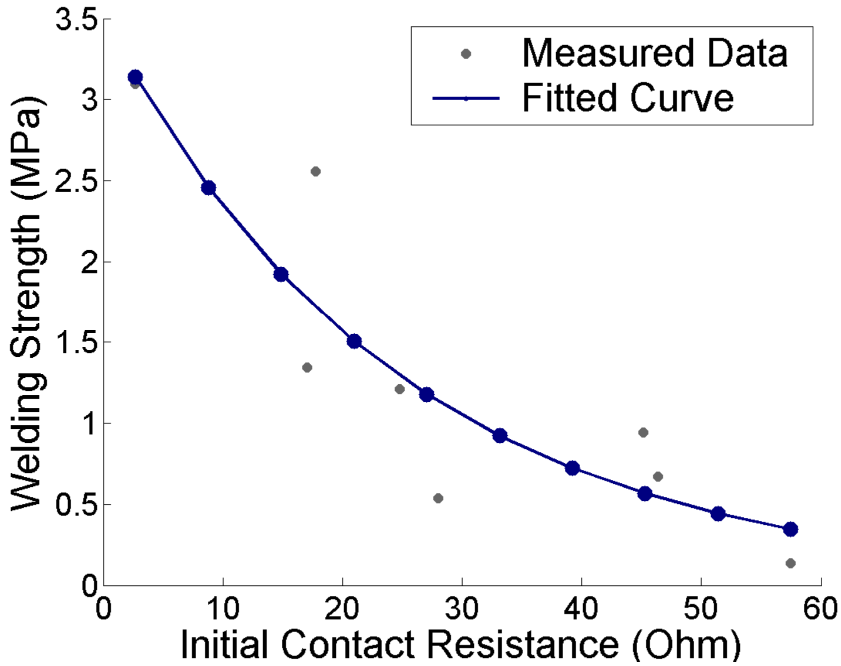


Figure 7. Welding strength with different contact resistance

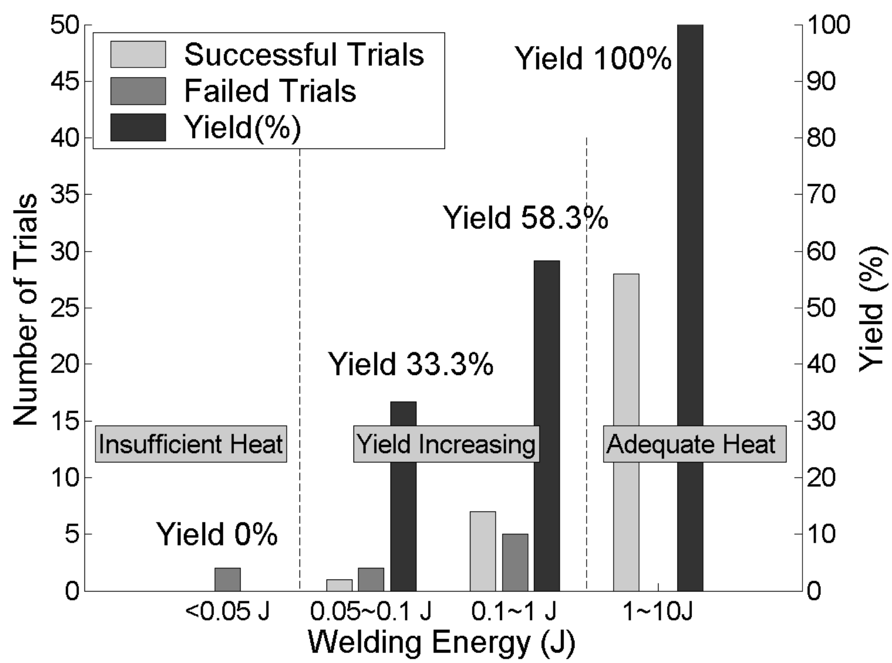


Figure 8. The yield of welding process under different energy

6. CONCLUSIONS

In this study, an electro-thermal micro actuators aided resistance welding is investigated successfully. It is found that applied welding energy is a key factor when the applied energy is above certain threshold value, 100% yield can be achieved in our cases. Also, higher contact pressure is shown to provide lower initial contact resistance and better welding strength. An integrated microactuator in resistance welding can be helpful to assembly micro structures in mass production. Assembly by resistance welding also allows electrical signal transmission through welded joints. Finally, the technique of thermal assembly proposed here could provide electrical connection and mechanical strength, which would be useful to assemble micro parts.

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