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Theory of the Solution of Inventive Problems for Flexure Design in Micro-Electro-Mechanical Systems

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Abstract

In this paper detail of the optimization of a flexure design which is used in many MEMS devices will be presented. Due to a difference in thermal expansion coefficients between the flip-chip bonded MEMS device and the substrate, cooling after bonding can cause the MEMS to buckle; It is necessary to decrease the influence of distortion by using the correct material selection, welding method, weld design, fixture design, temperature control and TRIZ. We can seek out principles that can solve the problem. It can be concluded that an optimal flexure design will include the longest fold length and smallest fold spacing possible. By solving the deformation problem of MEMS devices can promote the development of flip chip technology, and make for the further application of the TRIZ theory in the study of forestry equipment.

Keywords: *TRIZ conflict matrix, coefficient of thermal expansion, pile welding, parameter changes*

1. Introduction

With the advancements of MEMS foundry services and TRIZ tools, the flexure design [1] in MEMS devices can be cost-effectively designed. In this paper we detail the optimization of a flexure design that is used in many MEMS devices. Due to a difference in thermal expansion coefficients [2] between the flip-chip bonded MEMS device and the substrate, cooling after bonding can cause the MEMS to buckle. It is therefore necessary to decrease the influence of distortion by using the correct material selection, welding method, weld design, fixture design, temperature control and TRIZ as Figure 1 shows.

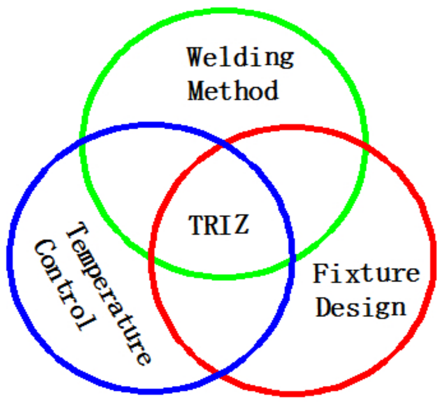

Figure 1. Welding Design Connection

Since micro-electronic components and micro-systems have a revolutionary impact on peoples' life, MEMS [4] tried to make mechanical components or systems, sensor, actuator and instrument equipment miniaturization. That can foresee MEMS can make a great difference to persons in the future. With the increasing integration of electronic components, package

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dimensions develop towards sub micron grade even deep sub micron. MEMS, photoelectron and micro-sensors have various forms, complex structure and non-standard, which puts forward a big challenge for package technology. To prevent the device (due to thermal mismatch) producing too much stress is the key problem in package technology, which leads to decreasing reliability in the processes of dynamic resource encapsulating. In order to solve this problem, TRIZ is used in package technology. This paper uses the LED of the infrared camera as the object of study and combines TRIZ conflict matrix (Table 1). Find the optimization of the parameters and the deterioration of the parameters, and then seek out a Principle to solve the problem.

Table 1. TRIZ Conflict Matrix

		The possible deterioration of engineering parameters					The invention creation principle	
		1	2	…	…	39		
The possible improvement of engineering parameters	1Weight of moving object	---	…	…	…	35,3 24,37	Separation	1
	2 Weight of stationary object	…	---	…	…	1,28 15,35	…	2
	…	…	…	…	---	…	…	…
	39 Production efficiency	35,26 24,37	28,27 15,3	…	…	---	Pure gas environment	39
							Compound material	40

2. Technology Innovation Theory Based on TRIZ Theory

TRIZ [5] is a method for creating a science. It is oriented to guide people to innovation. To operate and Implement according to the different problems, different stages, so the invention can be quantified and controlled. TRIZ analysis tools include ARIZ algorithm, Su-field analysis, conflict analysis and functional analysis. Those tools are used for analyzing, problem model and conversion. In the process of technical conflict, check the conflict matrix. Different control parameters (A value of 1 or 2) will produce different technical conflict (conflict 1 and conflict 2). Choose proper parameters in order to seek out a correct principle. Then apply the application of conflict matrix and invention principle to form the innovation principle solution (As shown in Figure 2).

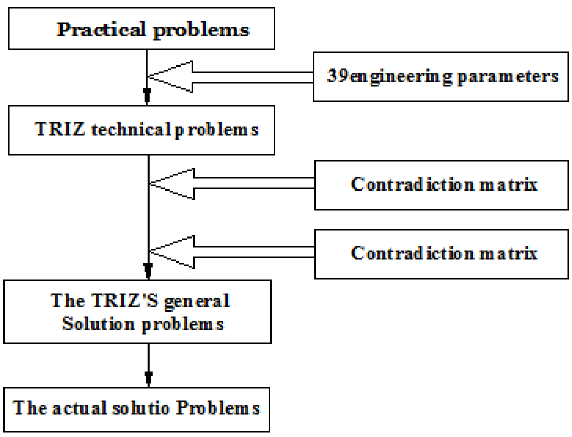

Figure 2. Conflict Analysis Process

3. Flexible Design Innovation Methods in Flip Welding Technology

3.1. Flip Chip Bonding Technology

Flip chip bonding [6-8] is that the chip electrode will be placed face down. The chip electrode must be in alignment with the substrate pads. Through heating and pressurizing method, after the got-up rack on the chip electrode or substrate pad in advance collapses or melts, the chip electrode is coupled with the substrate corresponding welding area. The advantages of flip chip bonding, ① Remove the connection request to the wire bonding. Shorten the interconnection distance. ② Improve the input / output (I/O) density. ③ Occupy small space on the circuit board. ④ Comply with the current trend of high density and miniaturization of microelectronic packaging. In the Flip TAB welding, the chip on the substrate installs upside down. As shown in Figure 2, compare flip TAB with the ordinary TAB, placing chip close to the metal cover is the biggest advantage, which can control heat effectively. For the ordinary TAB (Figure 3), flip TAB (Figure 2) has the assembly of higher density and the better radiation effect.

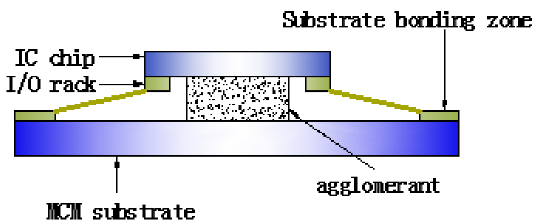

Figure 3. Flip TAB (down)

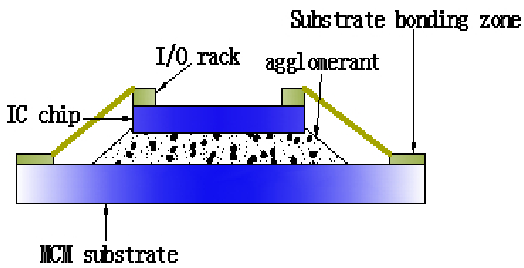

Figure 4. TAB up

3.2. The Reason of the Bonding Failure in Infrared Camera

Although a lot of MEMS devices used flip chip TAB, they also exist the bonding failure .The reasons as follows: There will be a compressive or tensile stress of the interface between different materials. The devices are often subjected to thermal cycling during operation because of a difference in thermal expansion coefficients between the flip-chip bonded MEMS device and the substrate. This reason can produce the periodic shear stress on welding surface during operation. Solder crack even the wafer crack would be formed caused by the periodic shear stress. Eventually lead to device failure due to thermal fatigue. In the chip and the bonding layer, the maximal thermal shear deformation [9] can be estimated by a formula.

$$S = D\Delta\alpha\Delta T / 2 * d \quad (1)$$

Here, S is the thermal shear deformation; D is chip diagonal size; d is welding layer thickness; ΔT=Tmax-Tmin, Tmax is the solidification of the solder wire temperature, Tmin is the lowest temperature screening device; Δα is the thermal expansion coefficients between the chip and the substrate material. When Δα is bigger, S becomes more. The increase of S will lead to buckle of the device more easily.

3.3. The Solution of the Bonding Failure in Infrared Camera

In this paper, we regard the welding process as the research object. According to the basic solving steps of the process innovation, discuss the flexure design innovation method of Welding technology. Solve the basic problems in welding process based on TRIZ conflict resolving theories.

The basic elements of welding technology innovation methods include conflict parameters and principles about welding process. The welding process of conflict parameters refer to the parameter having the opposite behavior in welding process. The principles can be received by these conflict parameters in TRIZ conflict matrix. According to the factors (affecting the welding process) and the flexure design [10], changing parameters (fold spacing, fold length) can reduce the warpage. Fold spacing and fold length can be shown in Figure 5.

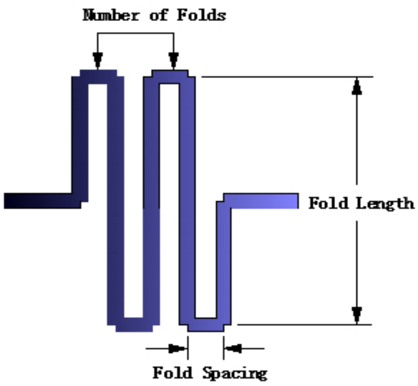

Figure 5. Parameters for the Flexure Design

Through technical analysis and abstract, 10 welding parameters and the principles of the welding process are summarized. In the practical application, use 2 parameters of the 10 welding parameters to show the two sides in the conflict with the internal performance. Use the conflict matrix to show conflict relations between parameters in the welding process. The specific contents are listed in Table 2.

Table 2. The Conflict Parameters of the Welding Process

Serial number	Parameters
1	Weight of non-moving object
2	Area of non-moving object
3	Volume of non-moving object
4	Tension, pressure
5	Stability of object
6	Reliability
7	Manufacturability
8	Convenience of use
9	Reparability
10	Adaptability

The conflict parameters are used in the field of welding technology innovation, a part from using TRIZ to explain and state in the welding process, another part from the summary of the welding technique (flexure design). In the actual welding process, because of the characteristic parameters of itself, there is the conflict between with the same parameters. Such as "speed" parameter, which contains the welding speed, wire feed rate, wire melting speed, cooling speed. When the wire feed speed is improved, the welding speed can be taken a turn for the worse. Therefore, innovative person considers conflict relationships between parameters comprehensively, in order to gain best innovation solutions of every parameter comprehensive performance.

In order to solve the conflict, the conflict relationships of 10 conflict parameters in the welding process are shown in Table 3. A row represents the optimization of the parameters and a column represents the deterioration of the parameters. The principles are listed in this table, the figures in front is the recommended choice principle.

Table 3. Welding Process Conflict Matrix Table

		The possible deterioration of engineering parameters									
		1	2	3	4	5	6	7	8	9	10
The possible improvement of engineering parameters	1										
	2										
	3										
	4			35,24				35,16			
	5										
	6										
	7										
	8										
	9										
	10										

Here, there are two pairs of conflict parameters. Seek out the principle in order to solve the problem one by one.

(1) Increasing the fold length can be used in flexure design.

The strong vibration of the micro scale atom reflects the existence of the temperature. The temperature gradient between different materials will produce the heat. Heat [11-12], as everyone knows, moves in three ways: conduction, convection and radiation. Conduction is the main mode of solid heat transfer. Introduce the first way: conduction.

$$q = -k * (dT / dX) \quad (2)$$

Here, q is the heat flow density along a given direction; k is the heat conductivity; (dT/dx) is the temperature gradient. Increasing the temperature gradient can produce more heat. Flexure design can be used to reduce the warpage by increasing fold length. The optimization of the parameter is the stress and pressure (4) and the deterioration of the parameter is the volume of non-moving object (3), so we can use parameter changes (35) in the conflict matrix (Table 3).

The explanation is given as follows; we can use the formula (3) to explain it.

$$\sigma = Ws / A \quad (3)$$

In the formula (3), σ is the shear stress; Ws is the shear force; A is the cross sectional area. The cross sectional area is proportional to the fold length, on the contrary, σ is inversely proportional to that of the cross sectional area. When we increase the fold length, A (the cross sectional area) will increase, in a result, σ will minish. Therefore, increasing the fold length can be used in flexure design to reduce the warpage.

In theory, we can confirm that increasing the fold length can reduce the warpage. We can prove it through experiments. Change the length of the fold length at different temperatures (0.7 ℃, 26.7℃), and we can get the amount of deformation value (Table 4, Table 5). We can conclude that the amount of deformation value is not always proportional to the fold length. That is to say, when the length of the fold length exceeds a value, increasing the fold length can cause the decrease of deformation. However, increasing the fold length can cause the increase of the cross sectional area. We can confirm that conclusion again.

Table 4. Thermal Deformation Values Measured at 0.7℃

Length（mm）	0	8	16	24	32	40	48	56
Deformation（um）	0	2.9538	4.3132	4.8852	5.8664	8.174	5.8664	4.8852

Length（mm）	64	72	80
Deformation（um）	4.3132	2.9538	0

Table 5. Thermal Deformation Values Measured at 26.7℃

Length（mm）	0	8	16	24	32	40	48	56
Deformation（um）	0	6.8972	10.275	11.454	12.606	15.325	12.606	11.454
Length（mm）	64	72	80					
Deformation（um）	10.275	6.8972	0					

A graph is drawn by these two tables. Through the analysis of the graph, we can draw a conclusion that this is an axis of symmetry (As shown in Figure 6).

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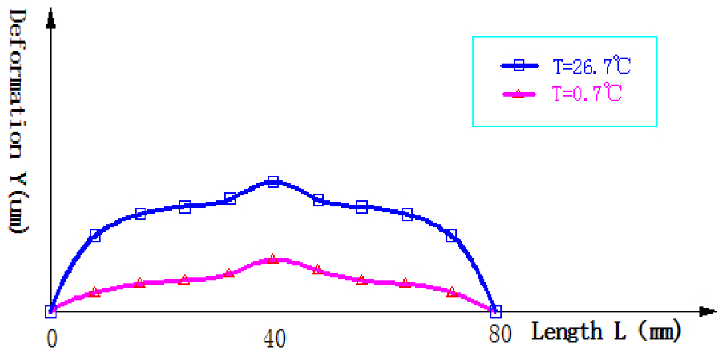

Figure 6. Schematic Diagram of Different Body Surface Thermal Expansion Values

(2) Reducing the fold spacing can be used in flexure design

Flexure design can be used to reduce the warpage by reducing the fold spacing. The optimization of the parameter is the stress and pressure (4) and the deterioration of the parameter is the manufacturability (7), so we can also use parameter changes (35) in the conflict matrix (Table 3). As is mentioned above, in the formula ($S=D\Delta\alpha\Delta T/2d$). When we reduce the fold spacing, D (the diagonal size of chip) will decrease, in a result, s will minish. Therefore, decreasing the fold spacing can be used in flexure design to reduce the warpage.

4. Summary

Solve the problem of chip bonding failure by using TRIZ conflict matrix. Break the traditional way (ignoring the characteristic parameters of geometric shapes) on its constraints, which encourage designs to consider the influence from several aspects (hardness, number of folds and so on). Using TRIZ theory to solve the problem of LED deformation can extend the life of the thermal infrared camera and promote the development of remote sensing technology, which is very helpful to obtain information of forestry and promote the application of TRIZ theory in forestry equipment.

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