Design and fabrication stable LNF contact for future IC application

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Abstract. Enable the design of a small contact spring for applications requiring high density, high speed and high durability. A low normal force (LNF) contact spring with high performance is fabricated using a unique combined MEMS photo resist lithography and electro fine forming (EFF) technology. Reducing a total contact material cost of a connector, a high-Hertz stress with LNF contact will be a key technology in the future. Only radius R 5μm tip with 0.1N force contact provides an excellent electrical performance which is much sharper than conventional contact. 0.30million cycle’s durability test was passed at 300μm displacement and the contact resistance was ≤50mΩ.

Keywords: LNF contact, high-Hertz stress, electro fine forming, NiCo, photolithography

1. Introduction

In present situation of electrical industry, miniature, light weight and high performance electronic devices production has been accelerated [1-2]. In order to increase the performance of a device the number of I/O pin is increasing. The size of those devices getting smaller. After introducing the Micro-Electro-Mechanical Systems (MEMS) it becomes possible to develop micro sized element for devices. On the other hand, miniature, light and high functional electronic devices have been developed using high functional LISs called SOC (System-on-Chip) [3-5].

Pogo pin is using in test socket area as shown in Figure 1. However, its contact force is approximately 0.5N. In this case 9806N/20,000pin is required for one board testing. This value is very...
high for the board and IC contact also. Sometime IC board or contact receives big damage and it is economically not acceptable. The user’s requirement is the load need to decrease at least half. If we can reduce this total load by 1/3 with high performance, that will be an excellent innovation. Therefore, an immediate solution is required.

![Figure 1. IC test socket application](image)

The commercial stamping process has size limitation that \( R \geq 200 \mu m = \text{low Hertz-stress} \) and it can’t meet the user’s requirements. Here is our innovation that, if it is possible to fabricate a very high Hertz-stress contact with LNF contact then it could make a stable contact resistance and this technology will help to reduce the material cost drastically.

We developed an excellent material Ni-Co to decrease active resistance of contact spring. Its durability performance is good. Although a suitable contact with appropriate \( R \) is the Key factor for LNF, it has not been optimized yet. We tried to optimize an appropriate \( R \) using several size \( R \) (5 to 200\( \mu m \)) by the same LNF contact which will be described in this paper. To fabricate this miniature contact, a MEMS technology is used instead of the existing pressing and injection moulding method because it is not compatible with the high-density packaging required in the advanced IT market. This research also focuses on a fabrication of micro interposer by combining UV thick resist photolithography and Ni-Co fine electroforming technology. This fabrication method is expected to develop high precision micro interposer and high-density packaging in mass production and is very essential to realize micro order devices.

The business value of this contact will be utilized on the Test Interface Connection area. For example, test sockets for IC-devices, test board I/F for IC-tester, and High speed board to board for I/O device. Furthermore, on a Medical Equipment area like 3D transducer interconnection for ultrasound, X-Ray sensor I/O for CT scanner is also necessary.

2. HERTZIAN CONTACT MECHANISM & DESIGN
A small spring with high reliability has to be developed to satisfy mentioned requirements which are focused in our research. Since sufficient contact pressure cannot be taken when the conventional material is used, although terminal size is made into a micro level, a reliable spring is not made. The commercial material Vickers hardness, as for example; Brass is 100–175, Phosphor Bronze is 150–200 are very low, where we needed the hardness more than double. Also a high Young’s modulus material should be chosen for this research. Considered all of mentioned problems, NiCo material is selected for our miniature size contact.
Figure 2: The geometry of Hertzian contact

Figure 2 shows a sphere (radius \( R \), elastic contacts \( v_2, E_2 \)) pressed by a load \( F \) into a flat substrate (with elastic constants \( v_1, E_1 \)). The load is supported over a circular area whose radius, \( a \), is given by:

\[
R = 0.721 \sqrt[3]{\frac{FE}{R_D}}
\]  

(1)

Where,

\[
E^* = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2}
\]  

(2)

The peak pressure under the sphere, \( \sigma_0 \), is given by:

\[
\sigma_0 = 1.5 \frac{F}{\pi a^2}
\]  

(3)

The stress field outside the contact zone has a tensile radial stress near to the surface which rapidly decreases, and soon becomes compressive, with depth [9].

Here \( R_D \): Diameter of the sphere, \( F \): Contact force, \( E_1, E_2 \): Young’s Modulus, \( v_1, v_2 \): Poisson’s ratio, \( \sigma_0 \): Hertzian stress.

Figure 3: Different R in equal diameter structure
In order to increase Hertzian stress [9-12] of contact point of the terminal have to be lower radius (sharp) to stick to the upper terminal. To investigate an appropriate radius R, we designed four types of radiuses such as 0.005, 0.025, 0.050, and 0.2mm with same size of the contact structure as shown in Figure 3.

In our case, the values of all parameters are, \( R_D \): 10\( \mu \)m, F: 0.16N, E1, E2: 180, 110GPa respectively, \( V_1, V_2 \): 0.31, 0.33 respectively. Calculating by using the equation (3), a compression stress of 19.14GPa is obtained. Using another larger diameter \( R_D = 50, 100, 400 \mu \text{m} \) are calculated by same equation, then the compression stress are 6.54, 4.12, 1.64GPa respectively. We can understand here, a small contact point obtains high contact stress and a steady contact resistance consequently. In this research, it verifies what kind of phenomenon occurs in a contact surface by using contacts with different R sizes.

3. FABRICATION:
The high aspect ratio micro interposer increases the contact resistance. Consequently, it improves the reliability of electrical signal transmission. A fabrication process of the micro interposer combining UV thick resist photolithography [11] and Ni-Co electro fine forming (EFF) technology were adopted to satisfy the above-mentioned specification. In order to make the terminal thicker, UV thick negative type photo resist is necessary. In this research we tried to fabricate a low resistance contact using a new process for a Ni-Co/Au/Ni-Co sandwich type structure as shown in Figure 4. The previous contact resistance was 200mΩ. The target of our contact is less than 50mΩ. Therefore, a thick contact and an Au sandwich type contact are decided to fabricate.
At first, I would like to explain here a basic type Ni-Co contact fabrication process. First, a Ni-Co bright electroplating (t=15µm) process is done on the base substrate (SUS) (1). A high sticking power is not necessary with this substrate. Second a UV thick photo resist is formed as a mould for the terminals (2). Then, the 1st electroplating (t=40µm) of Ni-Co or Cu is done in the mould (3). Au sandwich type structure will be electroplated here if necessary (4). In our case, 1µm Au layer is added for the sandwich contact. The 2nd electroplating (Ni-Co) is done for the structure in the mould, and the thickness is 45µm (5). Here the balance of sticking power of the 1st and 2nd electroplating is very important in order to remove the structure from the 1st electroplating. A neutral sticking power is suitable for here. The photo resist is removed (6). The transcript seat lamination is done to the top of the structure (7). Base structure removed from bright electroplates (8). Lastly, the structure is removed from the 1st electroplates (9).

3.1. Fabricated Structures
Figure 5 shows SEM (scanning electron microscope) photographs of the structures which are formed by the Ni-Co electroforming. The thickness of fabricated structures was measured by laser beam 3D microscope. The thickness was approximately 46µm (design 45µm), radius r=5µm (design 5µm). The edge surface was little bit rough but remained an acceptable level. Also a taper angle about 2% of the cross section of the photo resist as a mould for the terminals was observed. The current density of Ni-Co electroplating was 0.5A/mm² constant.

![Figure 5: SEM photographs of fabricated structure.](image)

4. Contact Force vs. Contact Resistance
The contact force and contact resistance is measured in different scenario to compare them. Figure 6 illustrate that the contact force is almost stable and same for all of the contacts where the maximum value was same around 0.16N. For each type of contact structure we measured n=5 samples. The lowest radius contact resistance, which is R 5µm, was the mostly stable compared to others. On the other hand, the largest R200µm was the very unstable. Also the R25µm and 50µm was unstable compared to the smaller R5µm contact.
Similarly we check these contact springs with Au sandwich type structure and measured by the same process. However, the result was almost alike. For the Au sandwich type the Au layer was only 1µm where the total contact spring thickness is 45µm. To find out the actual result further examination required.

5. Conclusion

In this research we figured out how to provide a stable contact resistance by LNF contact with very sharp contact like R=5µm with high Hertz stress will be needed than the larger contact R=25 to 200µm. The evaluation result proved that the capability of low normal force (LNF) which is 0.06N-0.15N at 0.45mm mechanical displacement by the contact point 5µm radius, the contact resistance was less than 50mΩ. This value is except conductor resistance. After finish the test, the surface condition of both parts (tip of contact and against electro pad) is analysed by SEM and mapping process. In the beginning of contact displacement the entering amount of R=5µm contact to the opposite electro pad was much higher than R=200µm at the same LNF. As a result, the braking ability of R=5µm contact of surface oxide film is much better than the larger one. For this reason, the contact resistance was stable.

Furthermore, we have done a durability test for 0.3million cycles of contact at 0.3mm mechanical displacement. The data of contact resistance was very stable, which is less than 50mΩ. This value is also except conductor resistance. There was no damaged of contact during the durability test.

In order to optimize an appropriate contact R with high Hertz stress for LNF contact, new technology photo lithography (MEMS) and NiCo electro fine forming technology is utilized to fabricate as a minimum R was only 5µm and thickness was only 45µm which is very difficult to fabricate by an existing commercial stamping method. As a result of using this process, we have fabricated successfully in these type of contact.
Also, to realize a high durability capable contact with high yield strength (more than 180Gpa), a suitable content Percentage of Ni and Co and electroforming current density is checked by some experiments. We have determined by the experiment that in order to fabricate an excellent contact, the ratio of Ni-Co is 8:2 and current density 0.5A/mm² is necessary. The Vickers hardness rate was more than 500Hv and it is 1.5 times larger from the commercial contact like phosphor bronze.

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