ENIG with Ductile Electroless Nickel for Flex Circuit Applications

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Electroless nickel coating generally breaks in a laminar parallel layered fashion. However, there are some baths available for electroless nickel coating that break into columnar shapes. Testing was conducted on both types of nickel on traces plated on flexible substrate using the MIT Bending Test method. A dramatic difference between the columnar and the laminar types of nickel, was observed in the number of cycles conducted. before any opens were detected in the traces. Clearly nickel with a columnar structure proved superior for flexing applications. In addition, testing was performed to assess the solder bonding strength and patterning properties, the performance of the columnar nickel was as good as the performance of conventional laminar nickel..

1. Introduction

Flexible substrates are becoming essential to electronic components that become increasingly lighter and more compact due to their degree of freedom. The most appealing feature of flexible substrates is ductility, and performance assessments may be made on bending tests or MIT tests.

Flexible substrates has been traditionally used for the purpose of connecting a mother board substrate and parts substrates and further applied to mounting of parts such as LCDs and ICs in recent years, thus increasingly expanding their applications.

In order to mount parts or connect connectors, electroless nickel/gold plating (hereinafter referred to as the "ENIG") is used. However, electroless nickel produces hard coating compared to base copper and often causes broken wires due to cracks.

This time, we conducted MIT bending tests using coating that breaks into layer shapes and coating that breaks into columnar shapes, and proved that flexibility comparable to that of the base copper could be obtained from the batch producing coating that breaks into columnar shapes. In addition, we checked for general solder bonding strength and pattern properties.

2. Test Methods

We prepared two types of rigid substrates and one type of flexible substrates for test pieces. For one of two types of rigid substrates, we used substrates produced by copper sulfate plating of approximately 20μm in thickness to a copper-clad laminate and fabricated solder ball pats of 0.5 mm in diameter on the substrates with the use of solder mask. We used these substrates for film thickness measurement as well as solder bonding tests and solder wet spread tests. For the other type of rigid substrates, we used substrates produced by etching up to approximately 10μm in thickness and then copper sulfate plating of approximately 10μm in thickness, and formed patterns with line and space of 50/50, 75/75, and 100/100μm and diamond-shaped patterns by etching, and further made holes in the patterns. We used these substrates for fine pattern assessments. For the flexible substrates, we used polyimide laminates of 25μ in thickness clad with electrolytic copper foil of 18μm in thickness and formed wirings of 0.05, 0.1, 0.5, and 1.0 mm in width on them by etching. We used these substrates for bending tests and MIT tests. For plating, we used commercially available plating chemicals from C. Uemura & Co., Ltd.. Table-1 shows this plating process. We used the NPG-1 from this company for a bath forming coating that breaks into columnar shapes (herein after referred to as the "ductility-compatible bath) to make comparisons with a bath forming coating that breaks into layer shapes (hereinafter referred to as the "conventional bath").

Table-1. Ni-P/Au plating process

Process	Chemical	Temp.	Time.
Cleaner	ACL-839	40 deg.C	5 min.
rince			
Soft etching	SPS type	25 deg.C	1 min.
rince			
Acid rinse	10% H_2SO_4	r.t.	1 min.
rince			
Pre-dipping	3% H_2SO_4	r.t.	1 min.
Activator	MNK-4	30 deg.C	2 min.
rince			
Electroless Ni (C)	Conventional	80 deg.C	*
Electroless Ni (N)	NPG-1	82 deg.C	*
rince			
Electroless Au	TAM-LC	80 deg.C	10 min.

* : Different thickness was made by changed the dipping time.

We verified all assessments by changing the nickel coating thickness and adjusted the nickel coating thickness by changing plating time.
We standardized the gold plating thickness to 0.05μm.

3. Precipitated Shapes

We plated the flexible substrates in the two types of baths; the conventional and ductility-compatible bath so that Ni/Au coating thickness will come to 5/0.05μm, cut the substrates physically using a cutter, and then observed their cross-section using a SEM.

As shown in Fig.-1, the results indicate that the conventional bath forms coating that breaks into layer shapes, while the ductility-compatible bath forms coating that breaks into columnar shapes. We considered that the results were related to the properties of elctroless nickel coating, and consequently conducted a variety of ductility tests

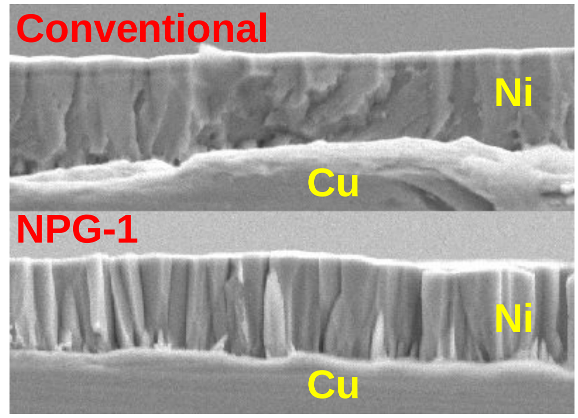


Fig.-1 SEM photographs of cross-section of electroless nickel coating
Top: Conventional bath, Bottom: Ductility-compatible bath

4. Bending Tests and MIT Tests

We conducted bending tests on flexible substrates after plating using wiring of 1 mm in width. To make comparison, we plated the flexible substrates with nickel to coating thickness of 2 and 5μm in the two types of nickel plating baths; the conventional and ductility-compatible baths. For bending tests, we wound the flexible substrate around a stainless steel rod of 1 mm in diameter in accordance with ISO 7438 and made assessments.

As shown in Table-2, the test results indicate that the flexible substrate plated in the conventional bath to 2-μm thickness did not break but substrate plated in the same to 5-μm thickness caused cracks, and that the flexible substrates plated in the ductility-compatible bath to 2-μm and 5-μm thickness caused no cracks.

On the other hand, for MIT tests, we used the same flexible substrates as those for the bending tests and made assessments using wiring of 0.5 mm in width. We plated the substrates with nickel to thickness of 1, 2, 3, 4, 5, and 6μm, respectively, and conducted the MIT tests in accordance with ASTM D2176. Table-3 summarizes the MIT test method.

As shown in Fig.-2, the test results indicate that the substrates plated in the conventional bath showed reduction in the number of cycles conducted until they caused broken wires as the coating thickness became thicker, but the substrates plated in the ductility-compatible bath showed no reduction in the number of cycles until they caused broken wires even though the coating thickness became thicker. Furthermore, data on the substrates with nickel coating thickness of 0μm are based on base copper wiring material without the ENIG process applied. This means the ductility-compatible bath provides the number of cycles conducted until broken wires are caused on the MIT tests compatible to that of the base copper material.

Table-2. Results of bending tests

Result	Conventional	NPG-1
2μm	OK	OK
5μm	NG	OK

SUS 1mm rod / plated 1mm line

Table-3. Method of MIT tests

Angle	135 deg.
Speed	175 cpm
Weight	500gf
R	0.38mm
Test board	0.5mm line

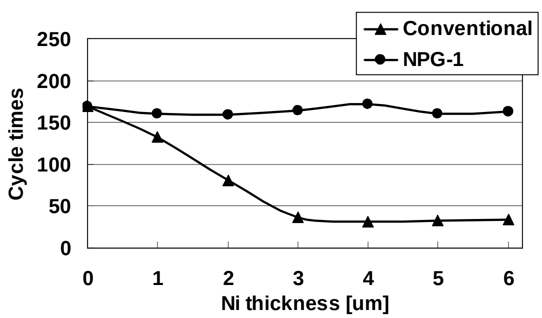


Fig-2. Results of MIT tests

5. Results of Solder Bonding Strength Tests

Table-4 summarizes conditions for solder bonding strength tests, and Table-5 and Fig.-4 summarize methods of solder wet spread tests.

Table-4. Conditions for solder bonding strength tests

Solder ball	Senju Sn-3.0Ag-0.5Cu 0.6mmϕ
Flux	Senju 529D-1 RMA type
Reflow instrument	TAMURA TMR-15-22LH
Reflow condition	1 times reflow at 240 deg.C top.
Ball pull instrument	Dage series 4000
Ball pull speed	1000μm/sec

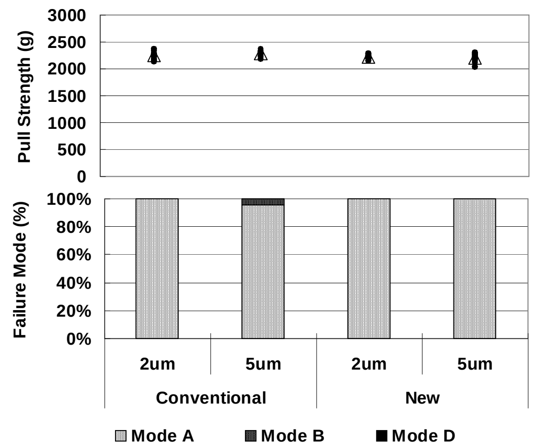


Fig.-3. Results of solder bonding strength tests

For the solder bonding strength tests, as shown in Fig.-3, the results indicate that the solder bonding strength and the destruction modes of the ductility-compatible bath had no differences from those of the conventional bath. The solder bondability was comparable to that of the conventional bath.

Table-5. Method of solder wet spread tests

Solder ball	Senju Sn-3.0Ag-0.5Cu 0.6mmϕ
Flux	Arfa metals R5003 R type
Reflow condition	45 sec. at 260 deg.C on Hot plate
Wetting rate	$= 4\pi r^2 / (4/3)\pi R^3$ [R = (a+b)/2/2]

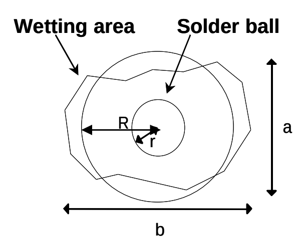


Fig.-4. Method of solder wet spread measurement

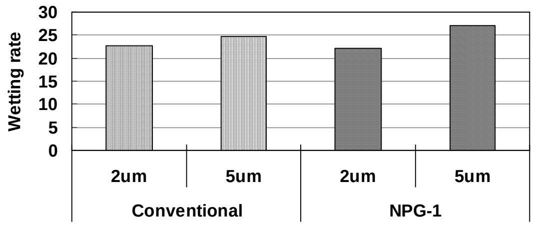


Fig.-5. Results of solder wet spread test

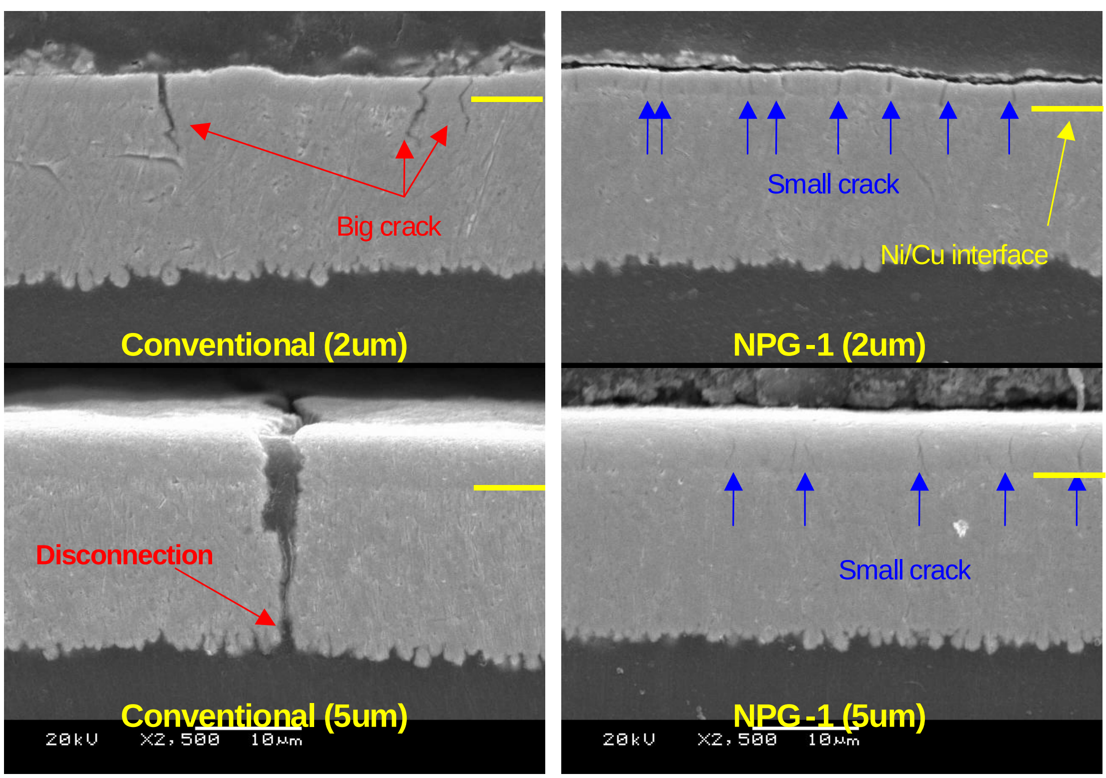
As shown in Fig.-5, the solder wet spread property was also compatible with that of the conventional bath.

6. Fine Pattern Property

Since the flexible substrate may need to have fine pattern property, we verified for the fine pattern property by plating base materials with line and space of 50/50, 75/75, and 100/100㎛ followed by checking of patterns for their links.

We prepared flexible substrates with nickel coating thickness of 2㎛ and 5㎛ and checked them for any pattern linkage through observation using a metallographic microscope.

As a result, there were no differences in fine pattern property between the conventional bath and the ductility-compatible bath, and both are in good condition. However, baths designed with no consideration given to the fine pattern property cause pattern linkage if the nickel coating thickness is 5µm and the line and space is 50/50.



FPC Line width: 1mm

Fig.-6. SEM photographs of cross-section after MIT tests

7. Conclusion

We conducted a wide variety of ductility tests using electroless nickel coating breaking into layer shapes and that breaking into columnar shapes, and found out that the coating breaking into columnar shapes showed definite advantages on the bending tests and MIT tests.

We suppose the reason is that the coating breaking into layer shapes focus stress on its one point when being bended and forms large cracks creating trigger for causing copper to break, but that the coating breaking into columnar shapes produces numerous small cracks to maintain the original ductility of copper and thereby causes no reduction in the number of cycles conducted until broken wires are caused due to the MIT tests.

As shown in Fig.-6, looking at the surfaces of the substrates on which the MIT tests were actually conducted, the substrates plated in the ductility-compatible bath have numerous small cracks, while those plated in the conventional bath have large cracks. The large cracks have reached copper and caused broken wires. This difference has adverse influence on values that resulted from the MIT tests.

Besides the aforementioned, as performance required for electroless nickel, we verified solderability and fine pattern property and found no differences from those from the conventional bath.

Since the applications of flexible substrates becomes increasingly diversified due to lighter and more compact requirements in recent years for electronic components, we believe that the ENIG process capable of clearing the ductility tests offers a new function.