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Connection Structure Using Rubber Connectors in the IoT Edge Platform, Trillion Node Engine

Kenichi Agawa, Ryoji Ninomiya, Minoru Takizawa
Toshiba Electronic Devices & Storage Corporation
Kawasaki, Japan
kenichi.agawa@toshiba.co.jp

Tokihiko Mori, Takayasu Sakurai
The University of Tokyo
Tokyo, Japan

***Abstract*—An IoT edge platform, where desired IoT nodes are realized combining several single-function printed circuit boards (PCBs) such as a sensor, microprocessor, and power supply unit with rubber connectors, is demonstrated.**

The PCBs are called "leaf PCBs" and their dimensions are typically 2 cm x 2 cm. Small rubber connectors are employed to connect these PCBs so that soldering is unnecessary and removable and replaceable structure is realized for customizability of IoT nodes. Three types of connectors, which utilize different conductive materials, are investigated under several kinds of reliability tests.

Keywords—IoT edge platform, rubber connector, Trillion Node Engine

I. Introduction

It is anticipated that 50-billion IoT nodes will be in use in 2020 and one trillion in the 2030s. In order to make this to be fully realized, establishing a platform for IoT nodes including hardware and software is crucial. Our platform will have two major significances. One is to empower individuals and Makers to embody their ideas and expand the IoT market, and the other is to empower engineers in industries enabling them a quick access to the IoT market and delivering their advanced technologies to people's life.

IoT sensor nodes require customizability as well as small size and low-power operation, because various functions are necessary for them according to their applications. We study on a platform realizing customizability easily, and investigate a system, where desired IoT nodes are realized combining several single-function printed circuits boards (PCBs) such as a sensor, microprocessor, and power supply unit. The PCBs are called "leaf PCBs" and their dimensions are typically 2 cm x 2 cm. Small rubber connectors are employed for connection of these PCBs so that soldering is unnecessary and removable and replaceable structure is realized on site outside factories. The dimensions of the connector are 13 mm (L) x 2 mm (W), while the leaf PCBs have 2-row-configuration 29 pins where a pin pitch is around 1 mm. We call the above-mentioned platform "Trillion Node Engine [1]."

In this work, we study robustness of contact resistance for three kinds of connectors, which have different conductive materials. Two kinds of connectors have wires as conductive portion and the other has conductive paste as it. We conduct several kinds of reliability tests, and find contact resistance of two kinds of connector is kept low under a temperature cycle test, even though rubber induces expansion and contraction during the test and this might increase contact resistance. Consequently, stable contact resistance is obtained between the leaf PCBs through the connectors.

Some samples of one kind of connector suffers from contact resistance increases under the temperature cycle test. We conduct observation on the rubber connectors and the test PCBs by an optical microscope and a scanning electron microscope (SEM) in order to investigate mechanism of the contact resistance increase. During SEM observation, energy dispersive x-ray spectrometry (EDX) is carried out to analyze contaminations on the rubber connectors and PCBs.

II. Concept of Trillion Node Engine

Rapid penetration of IoT nodes is expected, and an image of future IoT market is illustrated in Fig. 1. Outer region indicates IoT market expansion. Not only IoT devices provided by engineers of industries but also those provided by individuals and/or Makers are necessary for IoT market expansion. Thus, a platform or system, where individuals and Makers are empowered to embody their ideas and create their IoT prototype devices easily, is crucial.

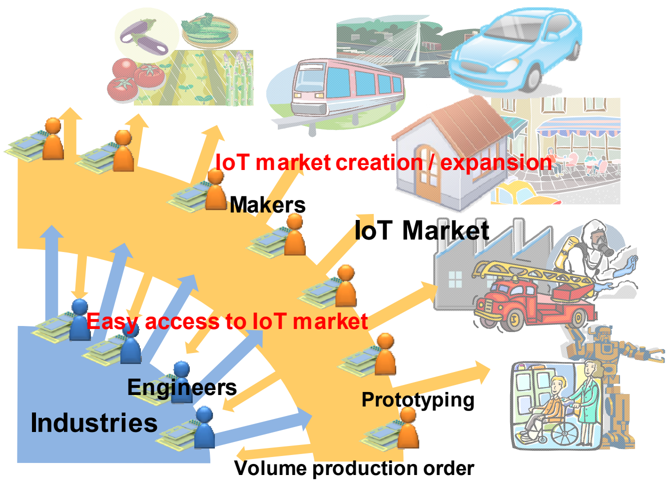

Fig. 1. Future of IoT market.

Diversity of IoT nodes is also inevitable for IoT market expansion. Supposing that one kind of IoT devices produces at most a million pieces, a million kinds of IoT devices are necessary to realize one trillion IoT devices as shown in Fig. 2. In order to deal with this diversity, the proposed IoT platform should support customizability of IoT nodes.

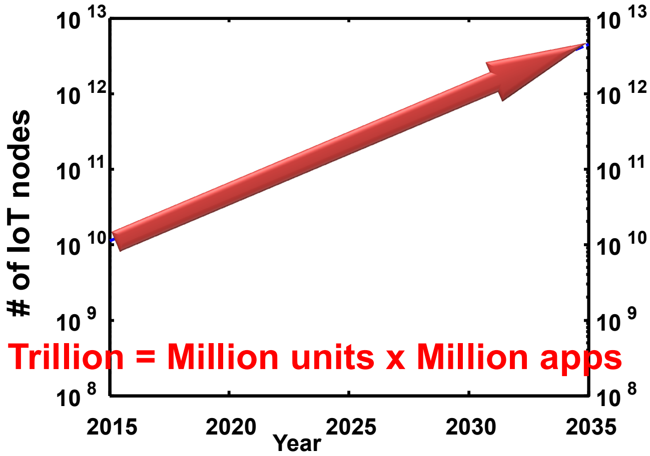

Fig. 2. Diversity of IoT nodes requires customizability.

IoT nodes typically contains four circuit blocks such as a digital circuit block, analog circuit block, power supply block, and wireless circuit block. Though it is possible that the digital circuit block is realized using a common microprocessor LSI, the other circuit blocks might result in various circuits. For instance, the analog circuit block should deal with a sensor or speaker or motor, and the wireless circuit block should deal with Bluetooth or Wi-Fi or LoRa or other various wireless communication standards [2-7]. If we try to create a dedicated LSI incorporating specific analog and wireless and power supply circuit blocks, a lot of time and cost are required. Thus, a scheme where desired IoT nodes are realized combining several PCBs with each specific LSIs, is desired.

Our Trillion Node Engine platform provides several PCB modules that is called leaf PCBs for this purpose, as shown in Fig. 3. A sample of IoT node module is completed after four leaf PCBs are assembled as shown in Fig. 4. The right-hand part of Fig. 4 shows four-direction side views of the sample module.

III. Rubber Connector and Leaf PCB

A rubber connector and leaf PCB are shown in Fig. 5. In our proposed connection scheme, what is limited for leaf PCBs is only the pad layout on them. The pad layouts on the surface and reverse side of PCBs are the same and the corresponding pads are connected via through holes. Electrical connection between two PCBs is realized setting a rubber connector between them.

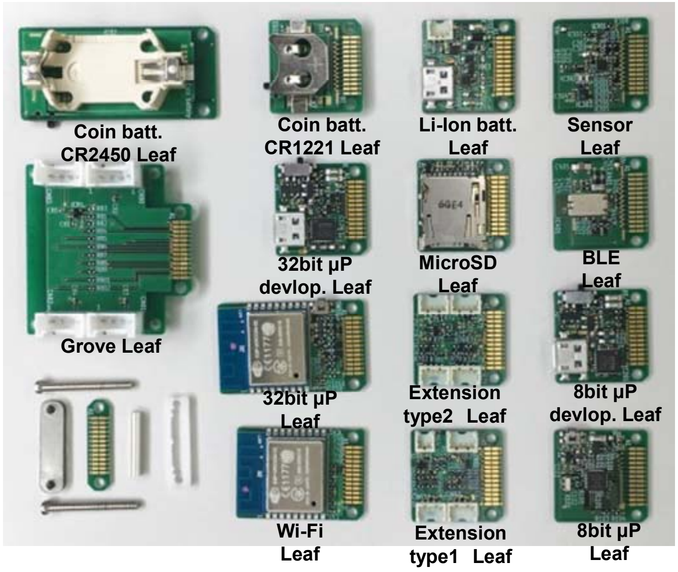

Fig. 3. Samples of proposed leaf PCBs.

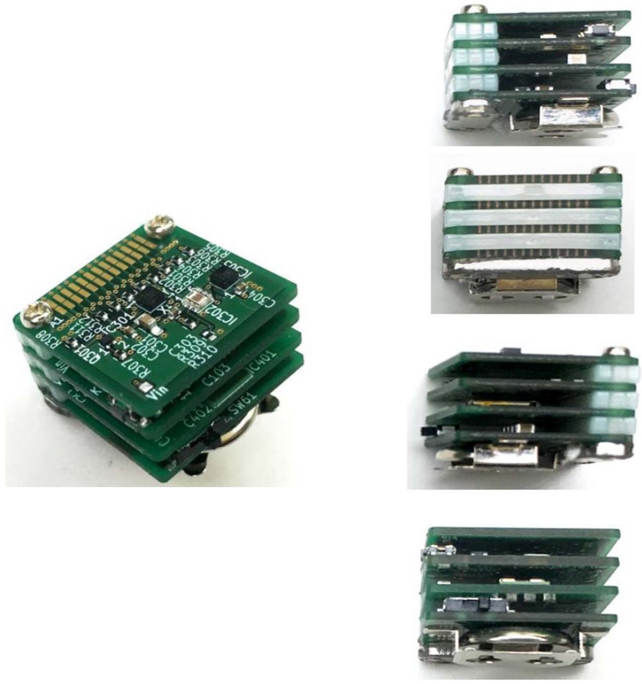

Fig. 4. Photographs of proposed modules.

The way how an IoT module is assembled using rubber connectors, holders, nuts and screws is shown in Fig. 6. Electrical connection between multi-layer PCBs is realized by multi-layer rubber connectors.

A magnified top view of the rubber connector (wire type) is shown in Fig. 7. Wires are arranged in 50 μm pitch, which is 1/20 less than a pad pitch.

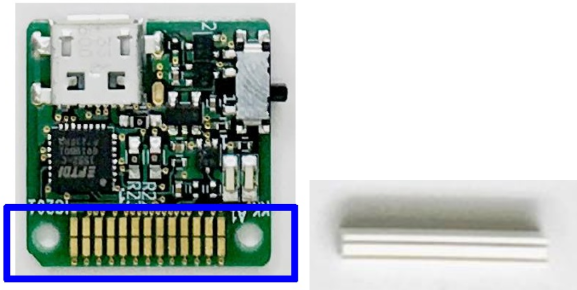

Fig. 5. Leaf PCB and rubber connector.

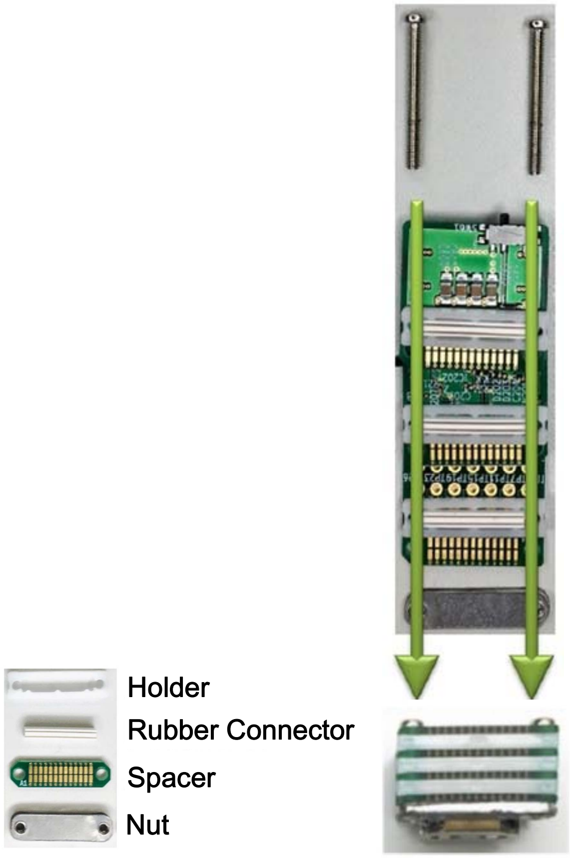

Fig. 6. Assembly of Leaf PCBs and rubber connectors.

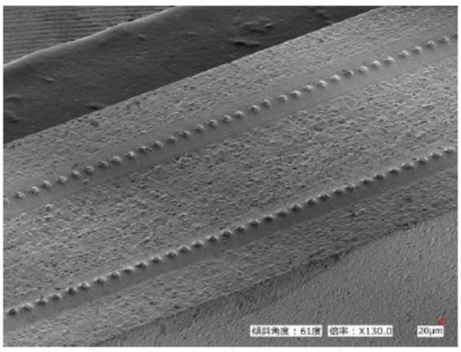

Fig. 7. Photograph of rubber connector.

IV. Contact Resistance of Rubber Connectors in Reliability Tests

A. Experimental Results

Robustness of contact resistance of three kinds of rubber connectors, which have different conductive materials, is studied. Two kinds of connectors have wires as conductive portion and the other has conductive paste as it. Three environmental tests are conducted as shown in Table 1. Leaf PCBs with daisy chain pattern are prepared and rubber connectors under test are set between two leaf PCBs so that all the contact resistance associated with the connector can be measured as series resistance.

As shown in Table 1, test samples under the high-temperature and high-humidity test do not show significant increase and/or decrease in contact resistance. Test samples under low-temperature test also do not show significant variation in it.

As for the temperature cycle test, we adopt two-hour transition between high temperature and low temperature because it might be reasonable in daily life and nature. Test samples of two kinds of connectors, wire type (A) and conductive paste type (B), do not show significant variation, however, a few samples of wire type (C) show increase in contact resistance.

TABLE I. Results of Reliability tests

Reliability Test	Connector Type		
	Wire (A)	Conduc-tive Paste (B)	Wire (C)
High Temperature High Humidity (85℃, 85%)	○	○	○
Low Temperature (- 40℃)	○	○	○
Temperature Cycle (- 40℃ ~ 85℃) *2-hour transitions	○	○	△

○ : No sample has contact resistance increase
△ : Some samples have contact resistance increase

B. Analysis for contact resistance increase

After the temperature cycle tests, we conduct observation on the samples of wire type (C) that show contact resistance increase by an optical microscope (OM) to investigate mechanism of contact resistance increase. Some black marks on the surface of the PCB pads are found as shown in Fig. 8.

Fig. 8 contains two pads, which are connected by a horizontal pattern for daisy chain pattern, and show line-pattern black marks at the lower left. We suppose that temperature increase and decrease induces expansion and contraction of rubber portion, and this causes wire movements, and the movements creates black marks on pads as a result.

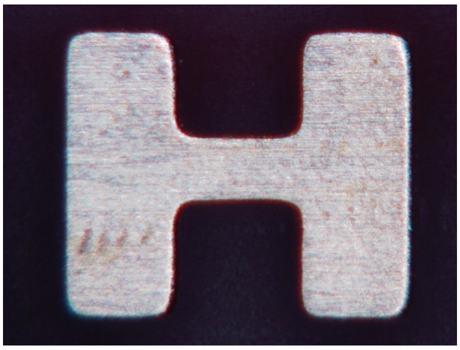

Fig. 8. Photograph of pads on leaf PCB after a reliability test.

Since the above-mentioned black marks seem contaminations on the pads, we conduct component analysis for them. During scanning electron microscope (SEM) observation, energy dispersive x-ray spectrometry (EDX) is carried out.

A magnified view of black marks by SEM is shown at the upper left of Fig. 9. The black marks seem raised contaminations. Cu element map detected by SEM-EDX is shown at the left of the middle row. Cu is supposed to be from wires of rubber connectors. Si element map is also shown at the right of the middle row. Si is supposed to be from silicone material of rubber connectors. Carbon element map is shown at the lower right. The map indicates carbon deposits or organic matter. For further analysis, time of flight secondary ion mass spectrometry (TOF-SIMS) is in execution.

V. Conclusion

Small rubber connecters are employed to connect PCBs in the formation of IoT edge modules, so that soldering is unnecessary and removable and replaceable structure is realized for customizability of IoT nodes.

Robustness of contact resistance for three kinds of connectors, which have different conductive materials, is studied under three kinds of reliability tests. Test samples of two kinds of connectors, wire type (A) and conductive paste type (B), do not show significant increase and/or decrease in contact resistance. Stable contact resistance is obtained between the leaf PCBs using the rubber connectors.

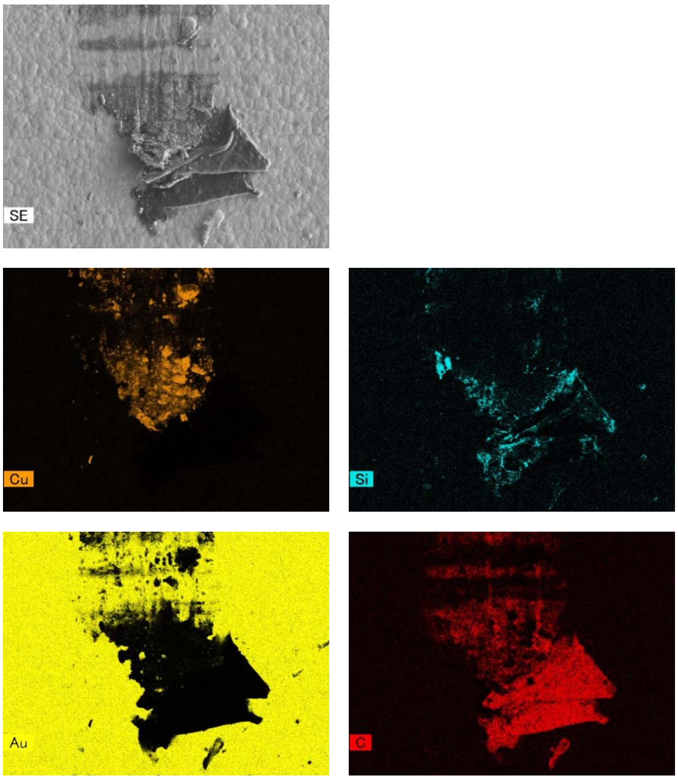

Fig. 9. Results of SEM EDX.

Acknowledgment

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