Manufacturing Method of Printed Wiring Board with High Heat Dissipation

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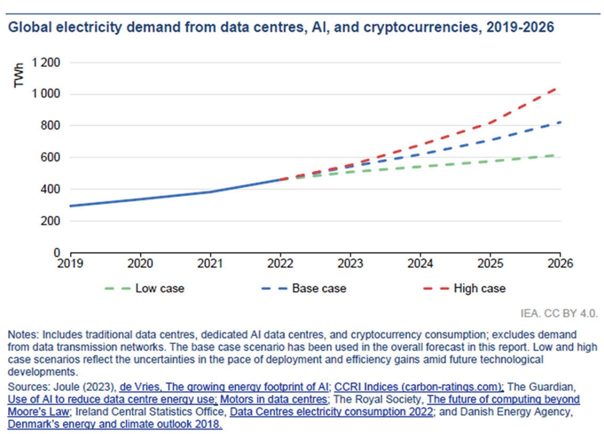
Generative AI, which has been attracting attention in recent years, collects large amounts of data, repeatedly learns, and constantly processes that information. As the data handled shifts from text to images and from audio-only to video, the amount of information continues to increase. Edge devices require more advanced information processing capabilities than before, and power consumption is also increasing. **Figure 1** shows the global data centers' electricity demand from 2019 to 2026[1]. In a high-case scenario, it is predicted that the electricity demand, which was 460TWh in 2022, will approximately double and reach 1,000TWh by 2026. Therefore, thermal design will become more important than ever in the development of related equipment, and heat transfer and heat dissipation structure will also be required for printed wiring boards (PWBs).



Source: IEA, "Electricity 2024 Analysis and forecast to 2026", p.31, Jan. 2024
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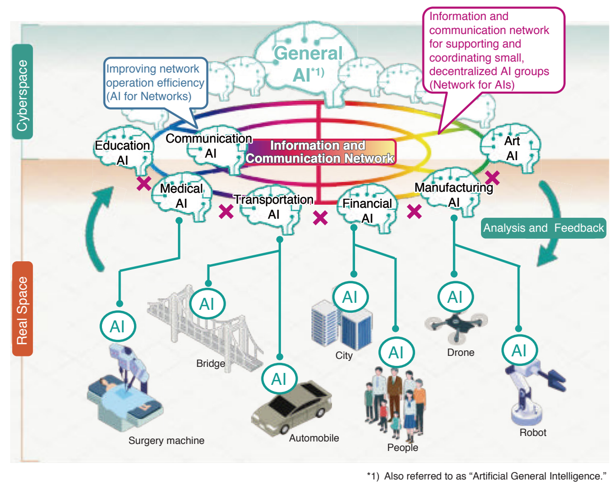
Figure 1. Global Electricity Demand from Data Centers, AI, and Cryptocurrencies, 2019-2026

Additionally, as shown in **Figure 2**, edge devices are constantly connected to the communication network, and coupled with the next-generation "Beyond 5G," communication volume is increasing day by day[2]. As a result, power consumption of communication equipment is increasing and the importance of thermal design is growing. This article describes the development status of the copper coin PWB, which is one type of high heat dissipation.



Source: Ministry of Internal Affairs and Communications, "2024 White Paper on Information and Communications in Japan"
https://www.soumu.go.jp/johotsusintokei/whitepaper/ja/r06/pdf/n227000f.pdf (in Japanese)
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Figure 2. AI's role in Beyond 5G (AI for Networks and Networks for AIs)

Characteristics of Copper Coins

Copper coins are pieces of copper that transfer heat between the front and back of a PWB. Heat generated from electronic devices can be transferred to the back of the PWB by placing copper coins directly under the electronic devices. Then, a heat dissipation member, such as a heat sink, can be attached near the copper coin or the copper coin can be made to contact the enclosure of the equipment to dissipate heat. In situations where a heat dissipation member cannot be directly attached to an electronic device due to size restriction of the equipment, or where a part of a device is a functional part, such as an image sensor or a light-emitting device, copper coins can be used to transfer heat to the back of the PWB, creating a structure with efficient heat dissipation. **Figure 3** shows a cross-sectional view of an image sensor module as an example use of a copper coin PWB.

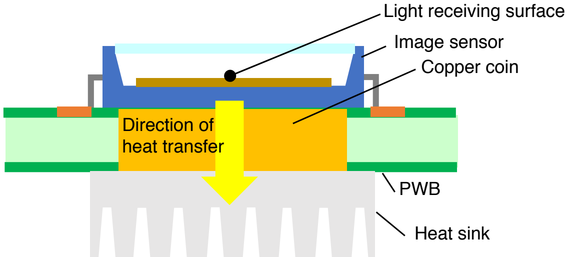

Figure 3. Cross-Sectional View of Image Sensor Module

OKI has been developing technology to enable the use of copper coins on PWBs of various structures. It is now possible to use copper coins in combination with thick copper foil PWBs[3] that have some or all of the layers made thicker to enhance heat dissipation, flex-rigid PWBs[4] that have flexibility to allow parts to be bent, and High Density Interconnect (HDI) PWBs[5]. OKI is also developing a structure in which copper coins are embedded in the inner layer of a HDI PWB, HDI layers are laminated on the front and back sides, and pads are arranged at high density while allowing heat to be transferred to the back side[5), 6)].

Development of Stepped Copper Coins

A stepped copper coin has different size surfaces on the front and back, and the surface area in contact with heat dissipation members is larger than the surface area in contact with electronic devices to improve heat transfer efficiency[7]. Pads and circuit patterns on a PWB connected to pins of the electronic devices are arranged around the copper coin on the side that contacts electronic devices of the PWB, whereas the back side has more space for placing a larger copper coin to improve heat transfer efficiency to the heat dissipation members. **Figure 4** shows the perspective and cross-sectional views of the copper coin.

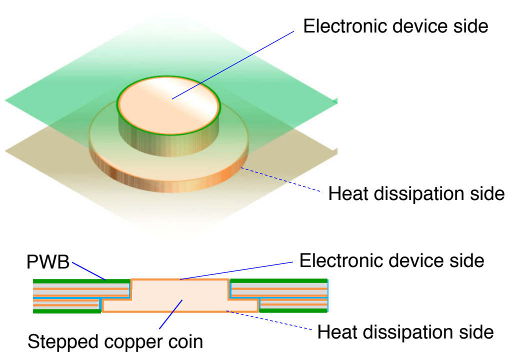

Figure 4. Perspective and Cross-sectional Views of Stepped Copper Coin

Manufacturing Method

The manufacturing method considered was to fill the gaps between the holes in the PWB and the stepped copper coins with heat-melted prepreg resin. The procedures are described below and in **Figure 5**.

(1) Circuit patterns are formed on layers L2, L3 and layers L6, L7 of the copper-clad laminate, and layers L1-L4 and layers L5 -L8 are each laminated with prepreg.

(2) Circuit patterns are formed on layers L4, L5. Holes slightly larger than the upper diameter of the stepped copper coin are drilled in layers L1-L4 and the prepreg, and holes slightly larger than the lower diameter of the stepped copper coins are drilled in layers L5-L8.

(3) Layers L5-L8, the prepreg with the hole, and layers L1-L4 are stacked in order from the top. The stepped copper coin is inserted from the top and laminated.

(4) Through-holes are drilled in layers L1-L8, circuit patterns are formed on layers L1 and L8, solder resist printing and silk printing are performed, and the board is cut into product shape. The composition of the prototype PWB is shown in **Table 1**.

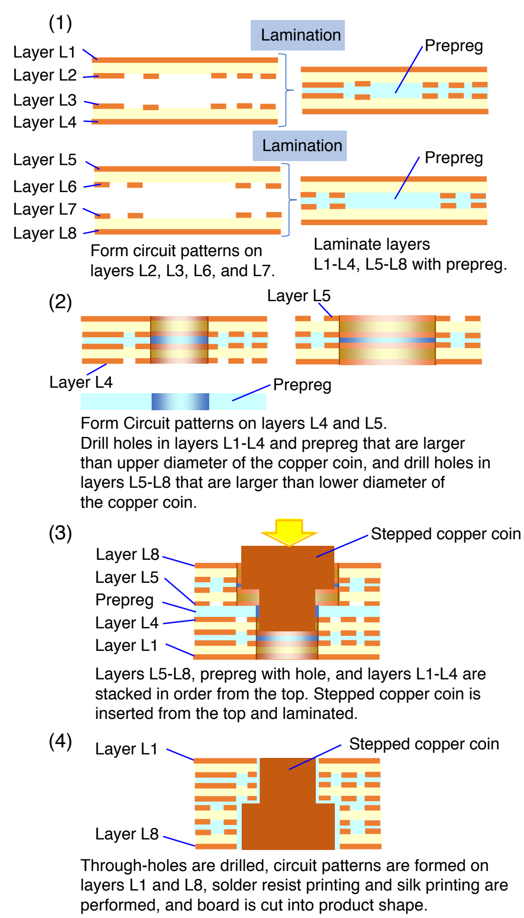

Figure 5. Manufacturing Method of Stepped Copper Coin PWB

Table 1. Composition of Prototype PWB

Layer	Composition	Interlayer Thickness	Copper Foil Thickness	Copper Plating Thickness
L1			35μm	30μm
	Copper-clad laminate	100μm		
L2			70μm	
	Prepreg	200μm		
L3			70μm	
	Copper-clad laminate	100μm		
L4			70μm	
	Prepreg	200μm		
L5			70μm	
	Copper-clad laminate	100μm		
L6			70μm	
	Prepreg	200μm		
L7			70μm	
	Copper-clad laminate	100μm		
L8			35μm	30μm

Prototype Evaluation

First, a prototype was made using a copper-clad laminate made of glass epoxy resin, which is a versatile PWB material often used in OKI's products, and prepreg. The stepped copper coin was found to be firmly fixed to the PWB. **Figure 6** shows a cross-sectional view of the prototype PWB near the stepped copper coin. The gap between the hole and the stepped copper coin was filled with prepreg resin, and no hollows or remaining gaps were observed.

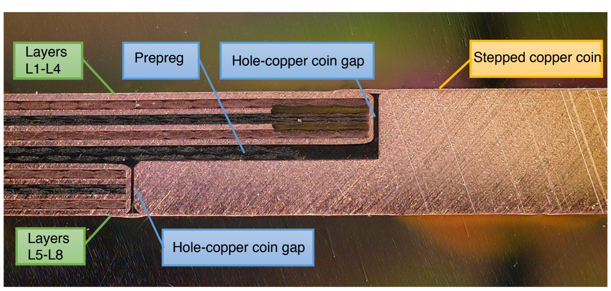

Figure 6. Cross-Sectional View Near Stepped Copper Coin

The next prototype was made using polyimide resin copper-clad laminate, which is a highly heat-resistant PWB material used in boards that require high reliability, and prepreg. When drilling through-holes in layers L1 to L8 after the second lamination (after embedding the stepped copper coins), some of the stepped copper coins fell off. The reason was thought to be the weak adhesion between the smooth copper that had not received roughening treatment and the polyimide resin. Therefore, when cutting the stepped copper coins, the finishing process to smooth the surface was omitted. A prototype was made again using polyimide resin copper-clad laminate and prepreg, and this time, the stepped copper coins did not fall off. In order to fix the stepped copper coins to the PWB more firmly, grooves or holes were formed on the side of the stepped copper coin. Using this method, another prototype was made using polyimide resin copper-clad laminate and prepreg. It was confirmed that the holes and grooves in the stepped copper coins were filled with prepreg resin, allowing for a stronger fixation.

Next, a thermal shock test was conducted on the PWB made from polyimide resin to evaluate insulation degradation. The board was exposed to a low temperature of -30°C and a high temperature of 125°C for 30 minutes each. This cycle was repeated 100 times. The evaluation checked whether the board maintains a resistance value of $1 \times 10^{8}\Omega$ or more after the test. As shown in **Figure 7**, multiple levels of structures B, C, D, and F, such as the gap between the circuit pattern and the copper coin, were formed on the evaluation board. Then, the minimum dimensions for which insulation degradation did not occur were used as specifications for the stepped copper coin PWB to obtain **Table 2**.

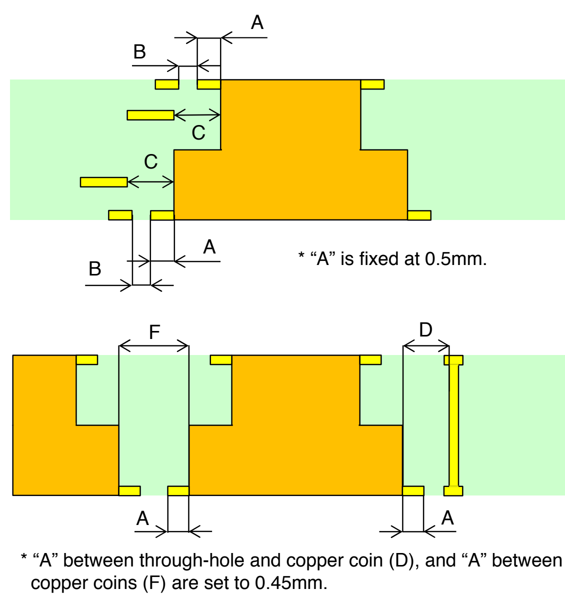

Figure 7. Structure of Stepped Copper Coin PWB

Table 2. Structure and Specifications of Stepped Copper Coin PWB

	Structure	Specification	Insulation Resistance After 100 Thermal Shock Cycles
B	Surface layer: between circuit pattern and land	0.15mm	$4.4 \times 10^{10} \Omega$
C	Inner layer: between circuit pattern and land	0.2mm	$2.8 \times 10^{10} \Omega$
D	Between through-hole and copper coin	0.65mm	$2.0 \times 10^{11} \Omega$
F	Between copper coins	1.1mm	$3.2 \times 10^{10} \Omega$

Evaluation Results

Stepped copper coins can be embedded in a PWB by filling the gaps between the coins and the PWB with heat-melted prepreg resin. It was confirmed that on a PWB made of heat-resistant polyimide resin, the stepped copper coins can be prevented from falling out if the surface of the coins are not smoothed out, and it was decided that grooves be formed on the stepped copper coins, which would be filled with prepreg resin to further prevent the coins from falling out. Additionally, a thermal shock test was performed on a polyimide resin PWB, and the specifications of the PWB were studied.

Conclusion and Future Studies

A manufacturing method was studied for stepped copper coin PWBs, which have higher heat transfer efficiency compared to conventional copper coins. Thermal shock tests were performed to evaluate the reliability and study the specifications of the stepped copper coin PWBs. The PWBs used in the aerospace field have thermal expansion coefficient that matches the ceramic devices to improve the connection reliability of solder connections[8]. OKI's future studies will look into manufacturing heat transfer members used on PWBs from materials with the same thermal expansion coefficient as the ceramic devices and consider a manufacturing method for embedding the heat transfer members in PWBs. ◆◆

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Authors

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TIPS 【Glossary】

Prepreg
Sheet-like PWB material made by impregnating glass fibers with thermosetting resin.

Copper-clad laminate
PWB material with copper foil attached to both sides of the prepreg.

Through-hole
Plated hole that penetrates a PWB and connects circuit patterns on the surface and inner layers.

Land
Conductive part formed around a hole in a PWB.

Glass epoxy resin
Sheet-like PWB material made by impregnating glass fibers with thermosetting resin containing epoxy groups.

Polyimide resin
Resin that contains imide bonds. For PWBs, thermosetting material is impregnated into glass fibers and formed into a sheet.