The Future Trend and Characteristics of Flexible Printed Circuit (FPC)

Mitsuru Watanabe[1], *Tadashi* Kanagawa[1] and *Hirofumi* Sakurai[1]

With household digital appliances becoming smaller, thinner, and more functional, it is thought that flexible printed circuit (FPC) will be used increasingly and there will be a greater demand for lighter, thinner, shorter, smaller, more flexible ones as well as ones with higher density. Furthermore, it is being increasingly required that consideration be given to environmental problems. Therefore, developments of FPC that are applicable for fine circuits and are multi-layered, soft/flexible, heat-resistant, having a low dielectric constant and are environment friendly is advancing.

1. Introduction

Recently, with household digital appliances, which are represented by the digital still camera (DSC), digital video camera (DVC), notebook computer, mobile phone, game machine and so on, becoming smaller, thinner, lighter and more functional, the adoption of FPC is becoming widespread.

Out of the total amount of production of domestic printed circuit boards (PCBs) in 2004, FPC occupied about 20% with a little over a trillion in number. And we predict that the production of FPCs will grow more than 10% per year in the future.

It is believed that FPCs are lighter, thinner, shorter, smaller, and in addition more flexible. And FPCs will be in greater demand owing to the progress made in having a higher density. Moreover, consciousness toward environmental problems is rising globally. The consideration to the European Union's environmental burden substance restriction might also have become indispensable and in order to meet these demands, there is an urgent need for FPC materials with the required characteristics.

In this paper, we describe the features of Copper Clad Laminate (CCL) and cover coat materials, which are the main components of FPC, the required characteristics of the materials for satisfying the specifications of FPC and the future trend. We have not described the stiffener, adhesive, etc, although they are also components of FPC materials.

2. Characteristics of each CCL

2.1. CCL

We should select suitable CCL by combining the right manufacturing method, the right kind of film and the right kind of copper foil, according to the application.

For the electronic applications of FPC, CCL that uses polyimide (PI) resin for the insulating film is generally employed from the point of heat resistance.

An FPC that does not do soldering work such as the instrument panel of a car, does not need heat resistance. Therefore, CCL that utilizes polyester (PET) and polyethylenenaphthalate (PEN) also exists. Here, however, we take up CCL that uses PI mainly.

CCL is structurally classified roughly into three-layer CCL and two-layer CCL. Three-layer CCL is the type that laminates PI film and copper foil by using adhesives of the epoxy or the acrylic type.

Two-layer CCL is classified into three types on the basis of the manufacturing method: the casting type which coats the PI varnish to copper foil, the lamination type which laminates PI film and copper foil by using PI-type adhesives, and the sputtering type which is plated with copper after vapor-depositing or sputtering a metal to the PI film. The main characteristics of each CCL are shown in Table 1.

2.1.1. Three-layer CCL

Three-layer CCL is in the mainstream today because its qualities and properties are stable and it

Table 1. Characteristics of each CCL.

Structure	Manufacturing method	Property			
		Heat resistance	Dimen-sional stability	Bend-ability	Price
3-layer	Lamination	Fair	Fair	Fair	Low
2-layer	Casting	Very good	Very good	Very good	High
	Lamination	Very good	Good	Very good	High
	Sputtering plating	Very good	Good	Fair	High

1 Process Technology R&D Department

Table 2. Characteristics of each cover-coat material.

Type	Feature	Advantage	Disadvantage
Coverlay film	CL is the material which coat thermosetting adhesives to the same insulating material as CCL. An epoxy type or an acrylics type adhesive is used. After processing a coverlay by die, CL is laminated on a circuit board and is cured by hot press machine.	Easy to handle. High durability. High bend-ability.	Use a die and a hydraulic press to process coverlay opening. Use hot press machine to cure CL. Difficult to laminate CL to CCL with sufficient accuracy. Difficult to control adhesive flow.
Thermosetting ultraviolet curing ink	Ink is printed on a circuit board by the screen-stenciling process etc, and cure it.	A die and a press machine are unnecessary. Process costs are cheap. Materials are cheap.	Difficult to form small openings. Inferior to bend-ability.
Photosensitive ink	Photosensitive polymer ink is printed, and an opening is formed by exposure and development, and cures it.	A covered layer can be thin. An opening can be small. Materials are cheap.	Inferior to the tenting-ability on plated through-hole. Inferior to bend-ability.
Photosensitive film	Photosensitive polymer film is laminated, and an opening is formed by exposure and development, and cures it.	Good tenting-ability on plated through-hole. A covered layer can be thin.	Materials are expensive. Inferior to bend-ability.

is cheap. The adhesives of epoxy and acrylic types are mainly used for three-layer CCL.

The adhesive of high Tg is used for CCL that have high bend-ability under high temperature. In order to decrease the environmental burden, halogen-free adhesive is used. Moreover, as the circuit width becomes finer, the demand for high adhesion adhesive and high migration resistance is increasing.

Recently, with improvement in the high-dimensional stability of PI film, its application to CCL is also increasing. A film thickness of 12.5, 20 or 25 μm is generally preferred. There are two kinds of copper foil, the rolled copper foil and the electrodeposited copper foil.

Since the characteristics of each copper foil are different, we chose a copper foil for use in FPC.

Rolled foil is used when high bend-ability is required such as in hard disk drive (HDD) applications, and electrodeposited foil is used when bend-ability is not required such as in camera applications.

However, a special electrodeposited copper foil was developed whose bend-ability improves by annealing. It is called high-temperature elongation copper foil. It is used in floppy disk drive (FDD) that does not require high bend-ability as HDD does. A thickness of 9-70 μm is applied in the electrodeposited and rolled foils. Copper foils of 18 and 35 μm thickness are the most common.

2.1.2. Two-layer CCL

By contrast, generally a two-layer CCL has better heat resistance, dimensional stability, and electrical property than a three-layer CCL. Therefore, the two-layer CCL is used for an FPC that requires wire-bonding ability and migration resistance like the one used for plasma displays.

Also recently, two-layer CCL is mostly used in the hinge part of a fold-up type of mobile phone. If a three-layer CCL cannot satisfy the required characteristics, two-layer CCL is mostly selected.

2.2. Cover coat material

In order to obtain insulation of the circuit conductor on CCL, to provide bend-ability and to protect from external environment (rust and crack), an insulating material, which covers the circuit surface and is called the cover coat material, is used.

Different kinds of cover coat material have different characteristics such as a coverlay film (CL), thermosetting ink, ultraviolet curing ink, photosensitive ink, and photosensitive film. The characteristic of each cover coat material is shown in Table 2. The use of CL is most widespread. CL meets the various demand characteristics such as general use, halogen-free, and high Tg due to the type of adhesives coated on the PI film.

The ink and the film of alkali development type photosensitive epoxy or acrylic resin apply for those FPC that require a fine opening area and a highly precise position.

Recently, the demand for halogen- and antimony-free materials that have high bend-ability, low restitution, flame retardancy (for UL), and high heat resistance is increasing.

At present, a cover coat material that satisfies all the demands has not been developed. In order to meet these demands, alkali development type photosensitive PI inks and films are desirable.

We expect that they will have machine characteristics equivalent to CL and substitute it in the future.

3. Required characteristics of FPC materials

In order to satisfy the performance of various products, FPC also require various characteristics.

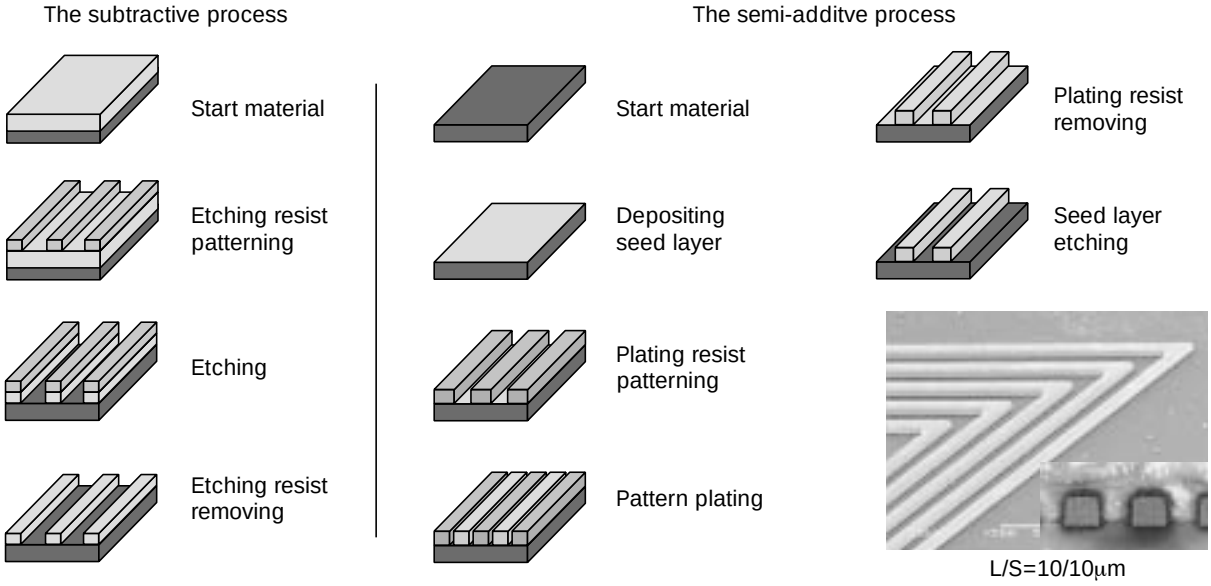


Fig. 1. Manufacturing method comparison of the subtractive process and the semi-additive process.

They are directly linked to each other. High-density wiring (fine circuit, multi-layer) and bend-ability (normal temperature, high temperature), low restitution, high-density part mounting, high-speed transmission, environmental problems, flame retardancy, etc. are identified as the required characteristics of the latest FPC. For each FPC, the required characteristics of FPC materials are described as follows.

3.1. Required characteristics of fine circuit FPC materials

In the case of FPC, the subtractive and the semi-additive processes are applied in order to form a fine circuit. Although the semi-additive process is generally superior to the subtractive process for forming a fine circuit, the subtractive process is advantageous in terms of cost and productivity. The outlines of each process are shown in Fig. 1.

In a fine circuit pattern, high migration resistance and high-dimensional stability are required.

In the case of the subtractive process, finer circuits can be formed by adopting a CCL that has a low profile and a thin copper foil. The comparison of etching characteristics resulting from the difference in copper foil profiles is shown in Fig. 2. Furthermore, the relation between the thickness of the copper foil and the pattern pitch is shown in Fig. 3. In the case of the semi-additive process, the etching characteristic of the seed layer and the peel strength influence the performance of the CCL.

3.2. Required characteristics of high bend-ability FPC

The data obtained by the evaluation of IPC mode as shown in Fig. 4 is the criterion of reliability for FPC of the optical pickup and the HDD magnetic head drive

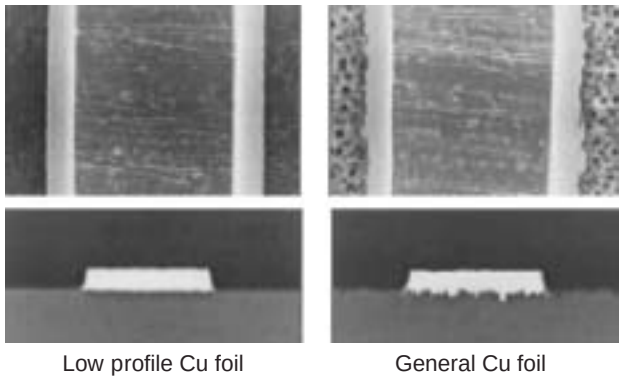


Fig. 2. Comparison of etching characteristics by a copper foil profile.

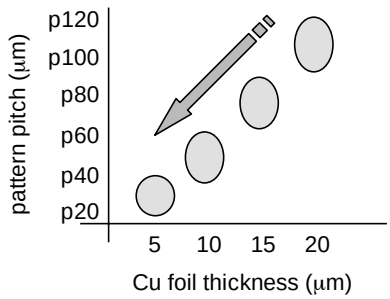


Fig. 3. The relation of copper foil thickness and pattern pitch.

part. Finally, it is based on the result of the evaluation by using the actual system. In an FPC of the hinge part of a mobile phone, the evaluation is performed in the hinge mode, which simulates the actual system as shown in Fig. 5. An example of the required characteristics is shown in Table 3.

The use of FPC in the HDD magnetic head drive and the optical pickup for cars has been increasing. Therefore, considerable high bend-ability under high temperature is required. In order to obtain these

Table 3. The required life span of the bend-ability.

Application	Bending mode	Required (time)
HDD	Normal temperature IPC	100 million or more
	80°C IPC	100 million or more
Optical pickup	Normal temperature IPC	100 million or more
Mobile phone	Alpha(α)-shape	100,000 or more
	Crank(U)-shape	100,000 or more

Table 4. Materials for high bend-ability.

CCL	Cu foil	Thin, many grain boundaries
	Adhesive (in three layers)	Thin high Tg, modulus of high elasticity, high peel strength
	PI	Thin
CL	Adhesives	Thin high Tg, modulus of high elasticity, high peel strength
	PI	Thin

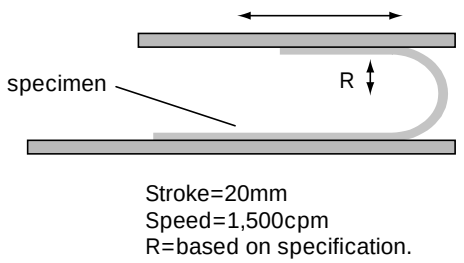


Fig. 4. The IPC mode.

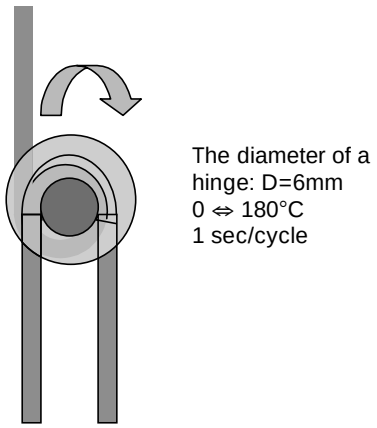


Fig. 5. The hinge mode.

superior characteristics, FPC materials as shown in Table 4 are needed. Moreover, the combination and the balance of CCL and CL influence bend-ability greatly.

In the case of FPC for HDD, high bend-ability, low outgas, silicone-free, low ion contamination, and cleanness are the characteristics that are required essentially. Furthermore, to reduce the power consumption of the drive, the demand for low restitution FPC is currently increasing. Therefore thinner and softer materials are being sought.

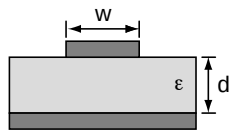
3.3. Required characteristics of high-speed transmission FPC

The demand for high-speed transmission FPC is increasing with the spread of high-definition display devices, etc. Impedance control is indispensable for the high-speed transmission FPC to suppress the degradation of signals by impedance mismatching. Impedance Z_0 demands an inductance (L) and a capacitance (C) as shown in equation (1).

$$Z_0 = \sqrt{\frac{L}{C}}\ (\Omega) \qquad \begin{array}{ll} L(H/m) & \text{inductance per unit length} \\ C(F/m) & \text{capacitance per unit length} \end{array} \qquad \text{.....(1)}$$

$$C \approx \varepsilon \frac{w}{d}\ (F/m) \qquad \text{.....(2)}$$

$$Z_0 \propto \sqrt{\frac{d}{\varepsilon w}} \qquad \text{.....(3)}$$



The capacitance (C) of the FPC depends on the conductor width (w) of the FPC, insulated layer thickness (d) and the dielectric constant (ε) of the insulating layer as shown in equation (2).

Therefore, impedance Z_0 is inversely proportional to the square root of the circuit width (w) and the dielectric constant (ε) of the insulated layer and is directly proportional to the square root of the insulated layer thickness (d) as shown in equation (3).

In order to extend the design flexibility of the circuit width, insulating material that has a low dielectric constant (ε) and a high layer thickness (d) is required as shown in equation (3). However, as described above, the demand for an insulating material with a low dielectric constant is increasing as material thickness tends to be thinner. The dielectric constants of general PI films are around 3.5 under 1 MHz. Some PI-based two-layer CCL and Liguid Crystal Polymer (LCP)-based CCL that have a dielectric constant of 3.0 have been developed.

Since the rate of moisture absorption of LCP is much lower than that of PI, LCP has the advantage of being little influenced by the environment. Therefore, LCP has attracted a great deal of attention as a low dielectric constant material.

3.4. Required characteristics of multi-layer FPC and R-F board

The following characteristics are required to laminate the materials and to establish connection between the layers:

1. Dimensional stability: alignment between layers.
2. Electrical property: insulation resistance and

migration resistance between layers.

3. Connection reliability between layers: drilling-ability and covering-ability of through hole plating. Note that the connection reliability between layers is influenced by the adhesion of adhesive, the misposition between layers, process conditions, etc. The influence of the kind of adhesives and base film is also large.
4. Heat resistance: part mounting.
5. Flexibility: flying tail portion of the FPC.

3.5. Required characteristics of mounting FPC material

The following characteristics are required for FPC materials to adapt to the various mounting techniques:

1. Heat resistance: delamination and swell do not happen as a result of the reflow process.
2. Peel strength under high temperature: circuit delaminations do not happen by contact with heat.
3. The modulus of high elasticity under high temperature: secure connection reliability.
4. Dimensional stability: ACF connecting position and high-density part mounting.

3.6. Required characteristics of FPC material following environmental considerations

Here, we summarize the materials in considering the environmental burden, the problems involved and their required characteristics.

3.6.1. Halogen-free materials

To satisfy UL flame-resistance standard in many FPCs, the halogen-based flame retardant that is cheap and has high flame-resistance has been used as the adhesive to laminate basis materials until now. But the halogen-based flame retardant generates poisonous gases such as dioxin at the time of incineration. Therefore, a material that uses a phosphorus-based flame retardant instead of the halogen-based flame retardant was developed. However, the adhesive of phosphorus-based flame retardant is inferior to that of the halogen-based flame retardant in many characteristics. It is necessary to evaluate them prudently especially because migration resistance and adhesion may decline. Among the CCL, the two-layer CCL has a halogen-free material generally, and many of them satisfy the conditions of migration resistance and adhesion.

3.6.2. RoHS-considered material

RoHS Directive is in order to restrict the use of certain hazardous substances in electrical devices, etc. If the product containing the restricted substance is exported to the EU, it will become a breach of law, and penal regulations will be applied. This will be legislated in the EU (enforcement in July 2006).

The following six substances are prohibited: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE). In FPC, a restricted substance, lead, is used in solder plating.

Therefore, in solder plating, the replacement by lead-free soldering, gold plating, and organic anti-tarnish is progressing.

Although alloy plating of tin, silver, copper, etc. is applied as lead-free solder plating, its further improvement is required since lead-free solder plating has problems such as the generation of a whisker and a high temperature of the reflow oven.

3.6.3. Phosphorus-free materials

Although phosphorus-based flame retardant is used as instead of a halogen-based one, use of the flame retardant may be restricted in the future.

3.6.4. Antimony-free materials

Although antimony is used as a flame retardant synergist and a catalyst, since antimony will be restricted by mainly the EU countries an alternative material will be needed.

3.6.5. Volatile organic compounds (VOC)

Currently, VOC is restricted to houses and car-related parts. The demand for VOC investigation as an FPC material is increasing and considering it will be necessary in the future.

VOC is present in the adhesive of FPC material in many cases. Recently, non-solvent type adhesive has also been marketed.

4. Conclusion

The demand for FPC is rising increasingly owing to the market available for terminal machines used ubiquitously in the society. We feel that the development of FPC materials is advancing at a rapid pace because of its advantages of fine circuits, multiple layers, flexibility, high-speed transmission, nil environment problems, and low cost.