Electrochemical Printing Technology (EPT) for Flexible Electronics

By Igor Kadija, ECSI Fibrotools, Inc.

ABSTRACT

ECSI Fibrotools, Inc. designs, builds and supplies wet processing equipment for micromachine and nano-feature R&D and manufacturing utilizing the patented FIBRO™ technology – Fiber Initiated Boundary layer Removal. This article introduces FIBRO™EPT – Electrochemical Printing Technology - a flexible electronic circuitry application of patent pending FIBRO™CET – Contact Electroplating Technology. EPT enables uniform, direct electroplating of pure metal on low-grade substrates without relying on peripheral electrical contacts - a regular method in any electroplating application[4-10].

Keywords: flexible, electronics, electroplating, printing

TECHNOLOGY

CET - Contact Electroplating Technology - enables uniform, direct electroplating of isolated patterns without relying on peripheral electrical contacts which are ubiquitous in today's electroplating process. The EPT application of CET addresses issues specific to flexible manufacturing. In f The overall thickness of the pattern and the FC/M electrode lexible electronic manufacturing low grade metal pastes are used in order to attempt to overcome the absence of peripheral electrical contact. Unfortunately, this comes at the expense of line resolution capability which stands in the way of flexible electronic evolution. A 20-30 micron paste line is necessitated where a 3 micron pure metal line would suffice (10:1).

With EPT each isolated structure is simultaneously charged by the main power supply via the patent pending electrode. Electroplating occurs directly on the seed layer enabling well-defined metal plating. The electrode is part of a sandwich structure which consists of the counter electrode (perforated or expanded Pt/Ti mesh); an open porosity, chemically stable polymer-structure sponge that is wettable and the electrode itself (a highly conductive Fiber Cloth, Web or Metal mesh (FC/M) with the number of contacts ranging from app). 200 psi to 5,000,000 psi plus, depending on specific pattern requirement.

While in operation the FC/M of the EPT sandwich is pressed against the flexible substrate containing the seed layer defined patterns submerged in the electroplating solution. Figure 1. Shows the schematics of the basic CET concept. The overall thickness of the pattern and the FC/M electrode is of the order of a few hundred microns.

This is an important aspect of CET technology since the structure can act as a thin composite with a large volume open porosity.

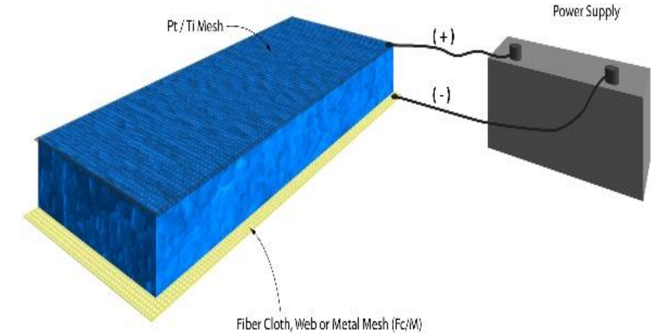

Figure 1. Schematics of the CET concept

After establishing intimate contact with the substrate, the powered rectifier generates an electrical field via the electrolyte soaked porous polymer. FC/M being an integral part of the porous composite structure with its negative polarization is causing the electroplating process to occur across the entire composite structure. The pattern is being plated uniformly across its entire surface. Thus, a low conductivity original pattern is transformed into a highly conductive 99.9% pure metal structure. Figure 2. shows the schematics of the electrical contact and the electric field distribution.

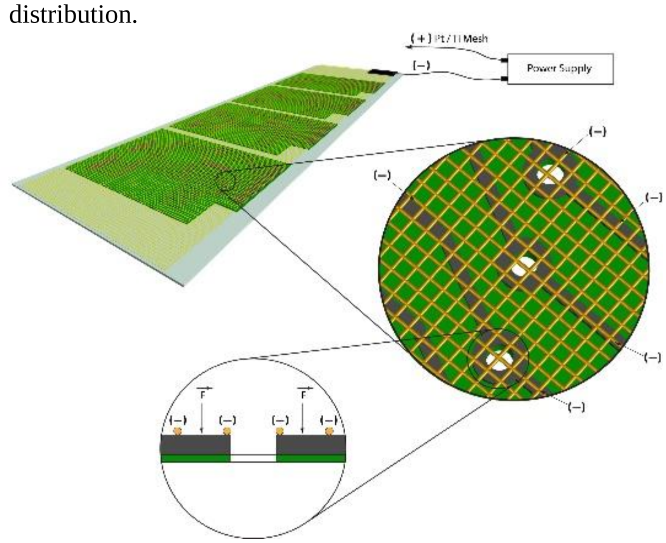

Figure 2. Schematics of the electrical contact and the electric field distribution.

In order to provide a sufficient supply of electrolyte and a satisfactory statistical distribution of contacts across the pattern, the sandwich can be reciprocating over the substrate. Reciprocation ensures that electrolyte is continuously exchanged at the interface. At the same time the contacts are repeatedly made across the pattern thus allowing for a more even distribution of deposit.

While processing the patterned substrates, metal deposition takes place over the FC/M electrode as well as over the pattern on the substrate. For most practical situations, the area of the pattern to be electroplated with metal is significantly smaller than the area of the FC/M which, by design, is the same or larger than the area of the flexible substrate. Hence the portion of the current utilized in depositing the metal over the pattern is typically a small fraction of the total current. Under these circumstances, several options are available for managing deposit distribution and maintaining optimal operating capability: (1) Reverse pulsing, (2) Flipping the sandwich and, (3) Roller plating combined with Reverse pulsing technique.

Figure 3. Shows the schematics of the reverse pulsing (RP) technique applied to maintain the operation of the CET device.

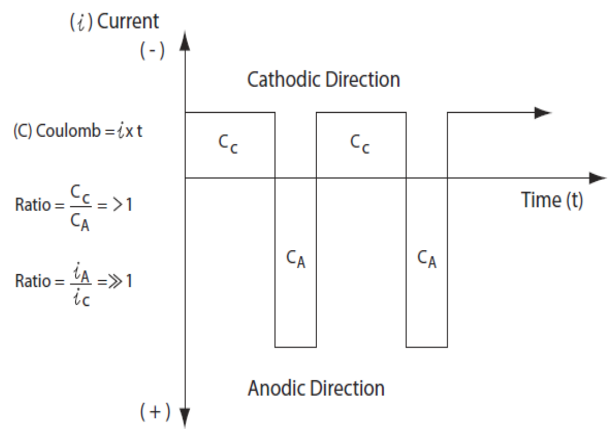

Figure 3. Schematic presentation of the reverse pulsing technique needed for maintaining continuity in CET operation

Two variations of RP can be applied; a) Continuous RP synchronized with reciprocating time and frequency and, b) RP application synchronized with "off" contact with the substrate.

With either option the plating, cathodic portion of the pulse is performed with the current density defined by the optimal conditions for the metal deposition However, the anodic portion of the pulse is designed for striping (or at least maintaining) the excess metal deposit over the FC/M.

The pulse is typically designed with a much higher current density but for a shorter period. The technique is known in the art of plating particularly in PWB processing. It has been practiced for a long time to remove excess plating at the electroplating edges of the through holes and at the sharp corners of the pattern.

The locations where the excess electric field, the so called "edge effect", forms an extra deposit and interferes with PWB performance.

Figure 4. Shows the electric field "edge effect" and the use of the same to maintain CET continuity.

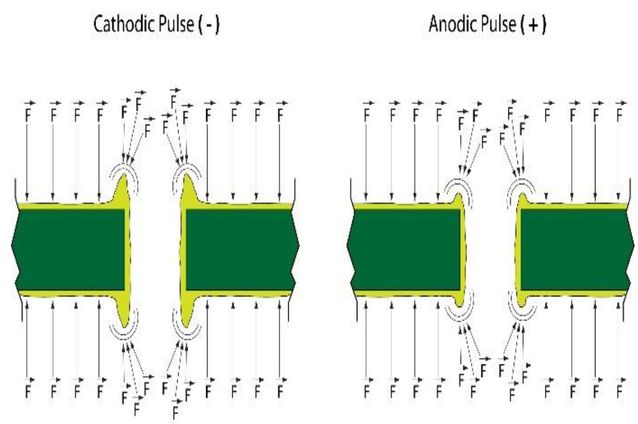

Figure 4. Anodic pulse preference for a higher electric field results in the removal of excess metal

While in intimate contact with the substrate the above RP mechanism allows electroplating of patterns and removing most of deposit from the FC/M electrode.

While operating as a cathode, one side FC/M may reach the point of saturation with the metal. By flipping the sandwich the same electrode can become the major source of metal for anodic dissolution - acting as a counter electrode after flipping the sandwich.

Roller plating option with RP implementation leads to a potential practical version of EPT for conveyorized processing. A series of CET sandwiches wrapped up in a roller form with RP method application can be operated in a conveyorized system for flexible electronics production. Due to the rolling action the level of immersion in the electrolyte can be maintained on a level not exceeding the thickness of the sandwich structure. Figure 5. shows the conveyorized EPT roller schematics for flexible electronics application. While the conveyor is moving the substrate through the processing chamber, the sequence of several rollers enables continuous electroplating of metal with increased statistical probability of even distribution of contact points across the pattern.

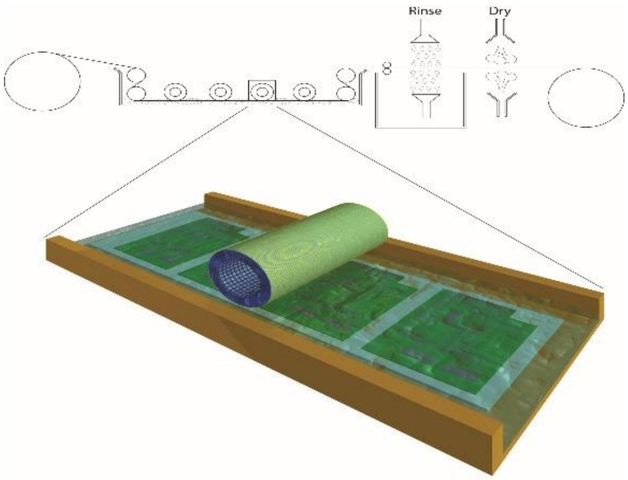

Figure 5. EPT Conveyorized processing for Flexible Electronics.

At this point it is worth mentioning the relationship of contact points and electroplated metal quality. Clearly, the contact points can be identified by scrupulous optical inspection of deposit. Again, the identification of contact points becomes more difficult, even at 1000X, with increased FC/M contact points and statistical iteration with reciprocating or rolling action. Nevertheless, no functional effect or correlation regarding the contact density has been detected regarding the conductivity of deposited metal.

CET and EPT EXAMPLES

Figure 6. shows the Direct Bonded Copper (DBC) substrates CET electroplated with Ni and Au. The Cu/ceramic substrates were electroplated with a CET sandwich first 10 min in Ni plating solution followed by 2 min Au plating solution resulting in 4 micron Ni and 0.3 micron Au. The resulting structure enabled dependable attachment to heat spreaders by soldering.

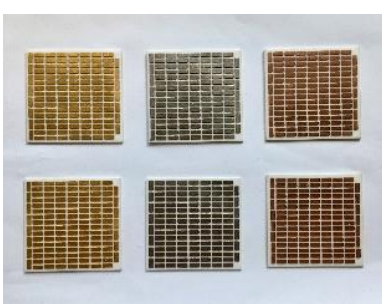

Figure 6. Ni and Au CET electroplating isolated DBC substrates

Figure 7. Cross sections of a CET electroplated PWB standard etching test pattern. 50 micron thick, 200 micron wide Cu line was electroplated with 7 micron Ni. The photo shows uniform plating distribution ending in complete encapsulation of the Cu line.

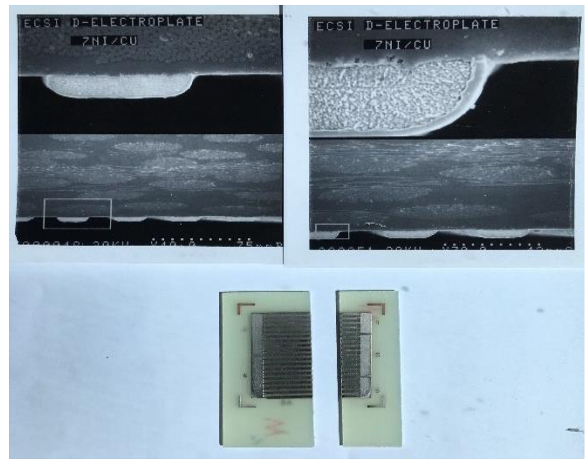

Figure 7. shows uniformity and completeness of isolated Cu line encapsulation with 7 micron Ni deposited with CET technique, 200x and 700x respectively.

Figure 8. shows PWB standard etching test pattern electroplated with Ni. The photo shows uniform Ni coverage across the substrate containing the minimum of 50 micron isolated line/space pattern.

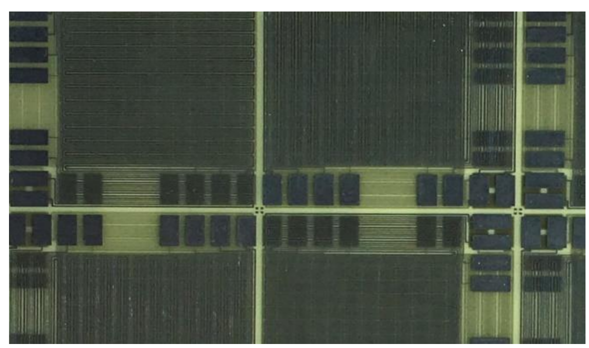

Figure 8. 50 micron PWB isolated standard etching patterns CET electroplated with Ni.

The flexible electronics industry is producing resistors by applying Carbon paste. We have used these patterns to demonstrate the conductivity upgrade by using CET technology with Silver electroplating. Figure 9 shows the results of using Carbon patterns over milar produced as Flexible electronics resistors after electroplating with CET method with Silver. After 2 times 4 seconds CET application a 5 mm long, 1.5 mm wide pattern 350 ohms resistance was reduced to 0.2 ohms.

Figure 9. Sample of Carbon resistor conversion to Silver wire with CET technology

An example of the implementation of the EPT technology is presented in a sample of electrostatic Carbon test images in Figure 10. A series of standard test patterns of Carbon patterns was electroplated with Silver. Uniformity across the various isolated interdigitated samples was achieved down to a 25 micron resolution.

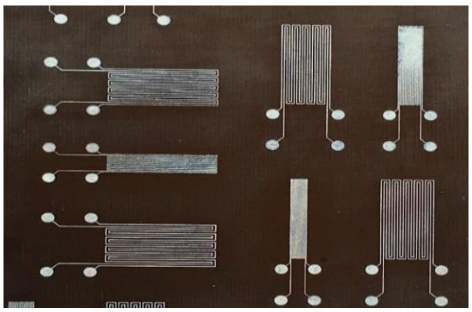

Figure 10. 25 micron resolution CET electroplating of standard Carbon patterns

EPT electroplating of flexible electronics devices was demonstrated on Laser Formed Electronic Device Patterns. Figure 11 shows the Silver plated high density pattern formed by Laser Ablation of Cu/milar laminate. The example shows the optimization from 100 ohms resistance over 5 mm distance and 2 mm wide line down to 0.01 ohms in 10 seconds after EPT plating.

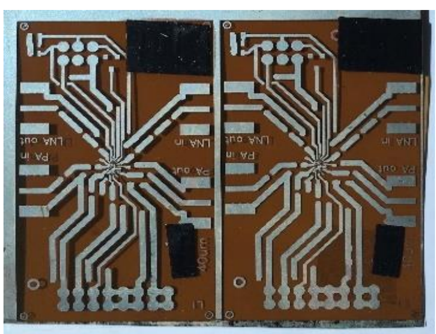

Figure 11. 40 micron resolution Laser Ablated sample of Cu/Milar laminate electroplated with Silver brought resistance from 100 ohms to 0.01 ohms in app.10 seconds.

CONCLUSIONS

A potentially viable implementation of Contact Electroplating Technology, CET, to Flexible Electronics has been demonstrated. The process is simple and can be applied to a large range of flexible electronic circuit and device applications.

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