Use of Carbon Nanoparticles for the Flexible Circuits Industry

Ying (Judy) Ding, Rich Retallick
MacDermid, Inc.
Waterbury, Connecticut

Abstract
FPC (Flexible Printed Circuit) has been growing tremendously in the past few years, especially in Japan and some other areas of Asia. In response to that growth, we have successfully developed a direct metallization process utilizing carbon nanoparticles. This technology has the advantages of lower cost, less maintenance and is more environmentally friendly than the conventional electroless copper process and most existing direct metallization technologies. In this paper, we will discuss in detail how this process can be used for the FPC application and the optimization that we have implemented.

Background
Flexible Printed Circuits (FPCs) have evolved to be one of the most cost-efficient solutions to the ever-increasing challenge of Printed Circuit Board (PCB) miniaturization. FPCs are typically made with polyamide material, which has superior dimensional stability, good heat resistance and a low dielectric constant compared to rigid FR-4 material. FPCs can be bent, twisted and flexed in three dimensions, and they are thin and lightweight. All those advantages of flexible circuits have made them extremely popular particularly at markets such as communications, computers, automotive, and medical instruments. World market for FPCs is projected to grow to US $5.0 billion in 2004[1]. Backed by 40 years in providing innovative solutions to electronic industry, our team has come up with a time proven reliable process to metallize FPCs for through-hole plating and other electroplating needs. This successful process has been empowered by its breakthrough chemistry utilizing carbon nanoparticles and its clever equipment designs.

Process Overview
Our direct metallization with carbon nanoparticles dispersion has a shorter process cycle of 12min, whereas traditional electroless copper process cycle is 50min long. Figure 1 illustrates how a throughhole is plated with carbon black process.

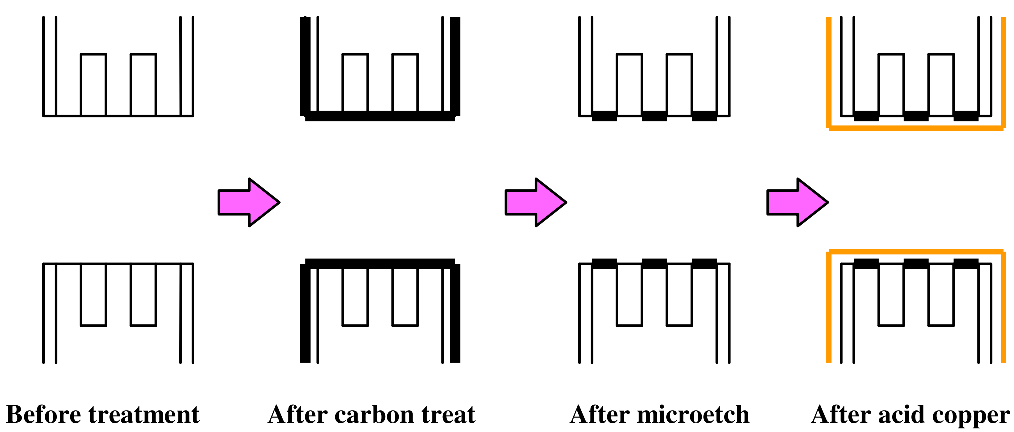
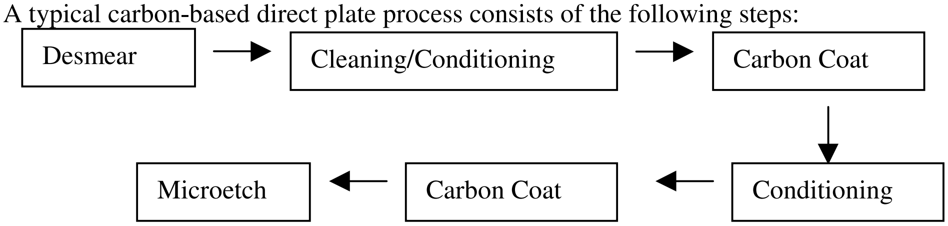


Figure 1. Schematic of throughhole plating with carbon black direct metallization process.

A typical carbon-based direct plate process consists of the following steps:



Enabling Chemistry
During over 10 years of research on carbon nanoparticles, we have mastered techniques to make stable dispersion with high performance. This aqueous carbon black colloid has a zeta potential of –61mV and particle size around 100nm. It has been widely used as direct plate for Printed Circuit Boards (PCB) for nearly two decades; and it has been regarded as the lowest cost through-hole metallization process available.

Desmear Chemistry
To apply this existing chemistry to the FPC metallization, the only challenge we have to face is the desmear difference. Unlike rigid boards, whose substrates are usually made with epoxy and glass, the flexible material today is mostly polyimide. The solvent swelling and permanganate treatment used for PCB can leave the sidewall of FPC throughhole unevenly roughened, like the picture shown below in Figure 2. In order to achieve ideal throughhole topography for polyimide, we optimized the operating condition and found that lower temperature of both solvent and permanganate gave best results as shown in Figure 3.

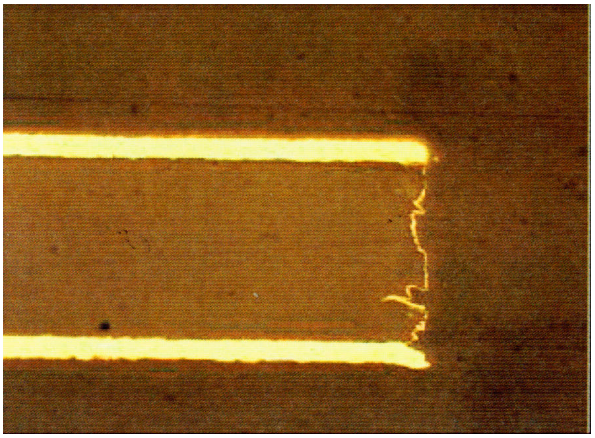


Figure 2. Cross section of a FPC sidewall after desmear under nonoptimized conditions.

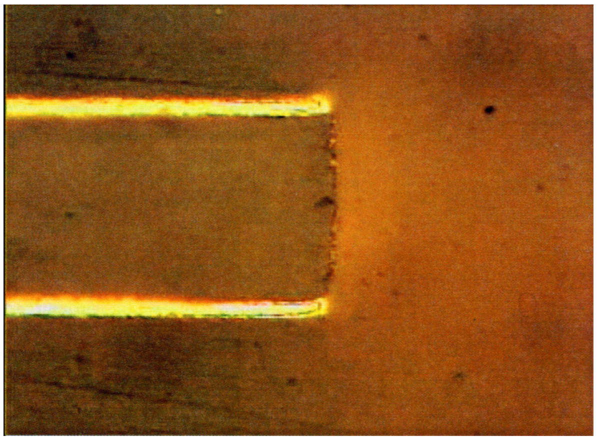


Figure 3. Cross section of a FPC sidewall after desmear under optimized conditions

Cleaning/conditioning Chemistry
The main ingredients of our cleaner/conditioner consist of a cationic polyelectrolyte and a surface-active agent. The surface-active agent lowers surface tension and provides detergency. The cationic polyelectrolyte gives a positive charge on the polyimide substrate surface. The polyelectrolyte is carefully selected with regards to its charge density and electrostatic interaction with the carbon black colloid.

Carbon Nanoparticle Dispersion Chemistry
This chemistry utilizes carbon blacks with primary particle size around 10nm and an anionic dispersant, which binds to carbon via physical absorption and gives it negative charge to form stable colloid. Good conductivity and holewall adhesion have been achieved on FPC board as demonstrated in the picture below (Figure 4.)

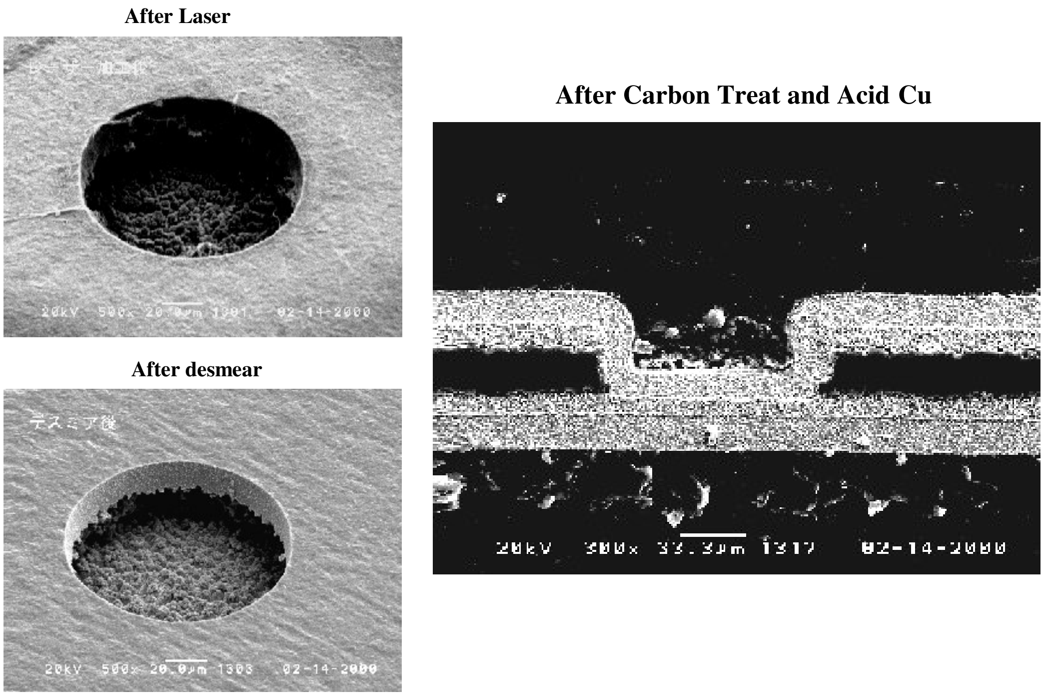
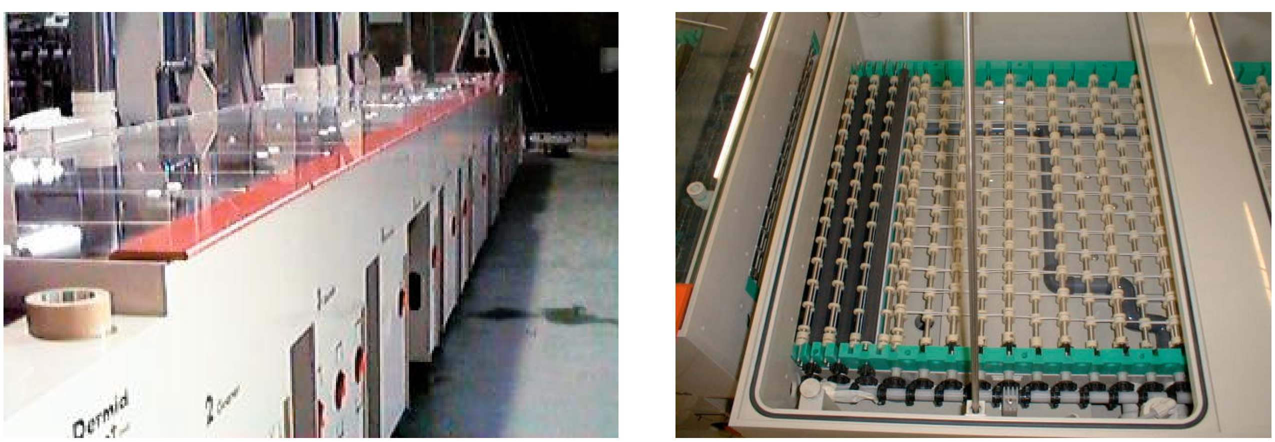


Figure 4. FPC boards processed through carbon dispersion.

<u>Microetch Chemistry</u>
This step is necessary in order to ensure best adhesion between electroplated copper and copper foil. Microetch utilizes oxidants to undercut copper and remove carbon from copper and also to roughen the copper surface for consequent electroplating or dry film processing. Peroxide was the oxidant that we have been using for our studies with FPCs. However, persulfate based microetch is also be feasible for this application.

Enabling Equipment
This carbon black process has been highly automated with horizontal conveyorized equipment. The equipment to enable FPC capabilities is shown in Figure 5.



A B

Figure 5. Overall equipment line for FPC carbon direct plate (A). The roller designs to enable FPC capability (B).

All the modules are enclosed, therefore, operators will not be exposed to any chemicals. In order to process thin FPC, the machines are modified in a number of ways to effectively hold thin laminate in place without causing warp. Our current equipment now is capable of processing thin flex boards with 50micron thickness, and at the same time, the same machine is capable of processing rigid boards.

Results and Discussions
With the combinations of breakthrough carbon nano technology and clever equipment designs, this carbon direct plate has been very successful in FPC processing.

<u>Good adhesion to substrate</u>
Satisfactory carbon coverage on both polyimide and adhesive substrates has been achieved as shown in Figure 6.

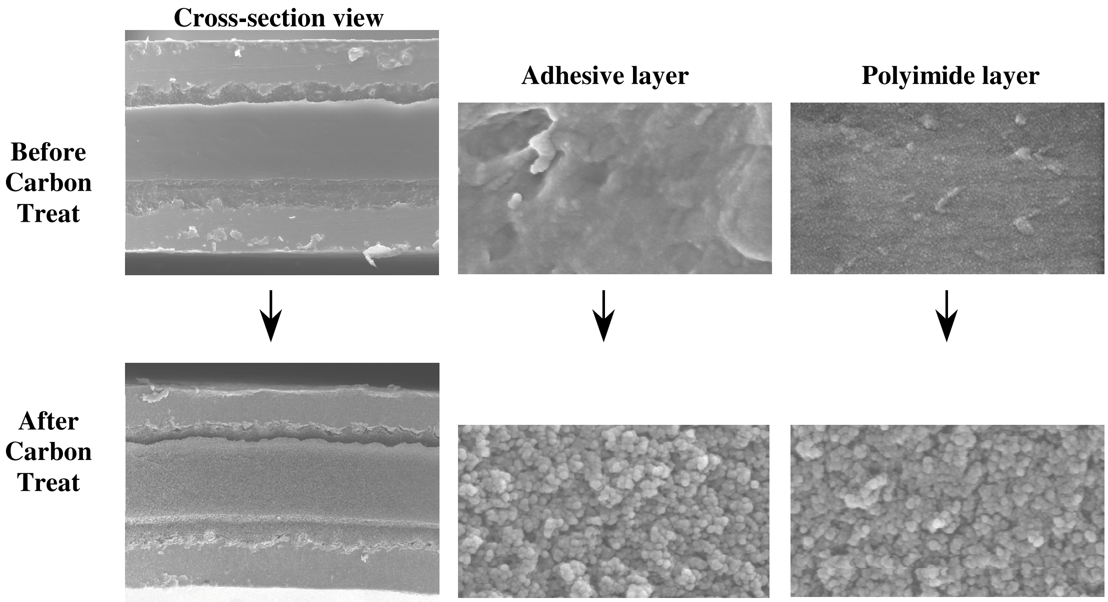


Figure 6. SEM images of cross-section view of a flex board before and after carbon coat.

<u>Good reliability</u>
The reliability of this carbon direct plate process has been tested according to various different standards and results are shown below.

Test	Test Method	Qualify	Cycles	Results
Solder Dip	IPC-TM-650	2,6,8	6	Passed
Thermal Shock	IPC-TM-650	2,6,6	400	Passed
Solder Rework	IPC-TM-650	2,4,36	5	Passed
Fluidized Sand	AT&T (heat shock)		40	Passed

No defects were found after 5 times solder float at 260°C as shown in Figure 7.

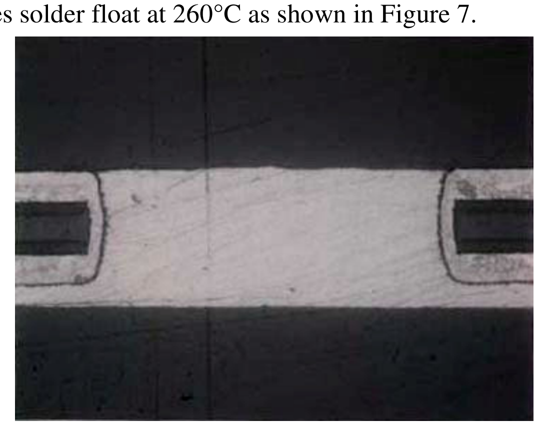


Figure 7. Cross-section of carbon treated FPC after 5 times solder float at 260°C for 30sec.

<u>High technology capability</u>
Although the conductivity of carbon is not as good as copper, equivalent performance to that of the electroless copper has been achieved with this carbon direct plate process. A few examples of carbon metallized high respect

ratio through-holes and microvias are shown in Figure 8. And Figure 9 demonstrates an example of multilayer flex processed through carbon direct plate.

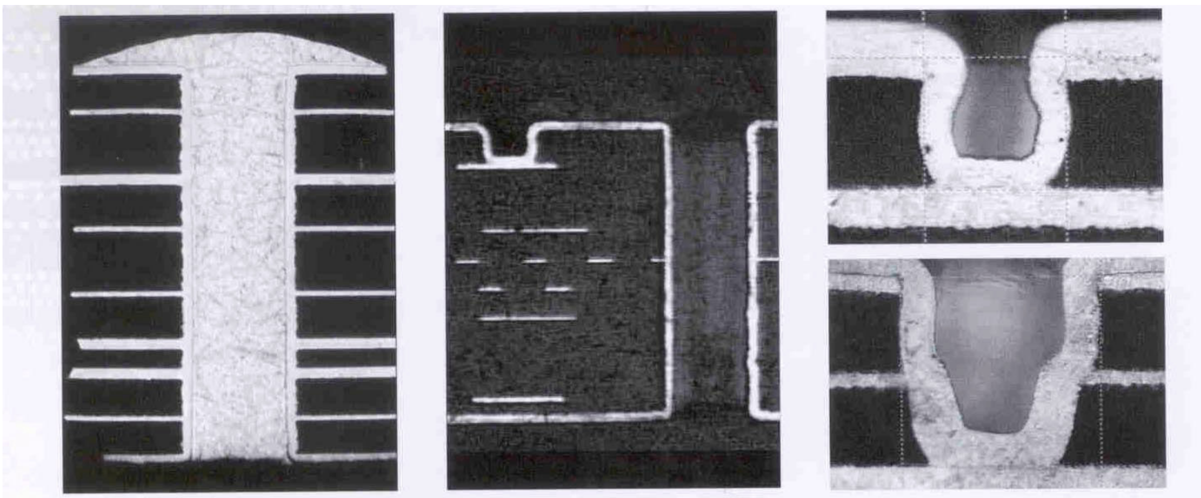


Figure 8. Cross-sections of high aspect ratio through-holes and microvias metallized by carbon nanoparticle dispersion.

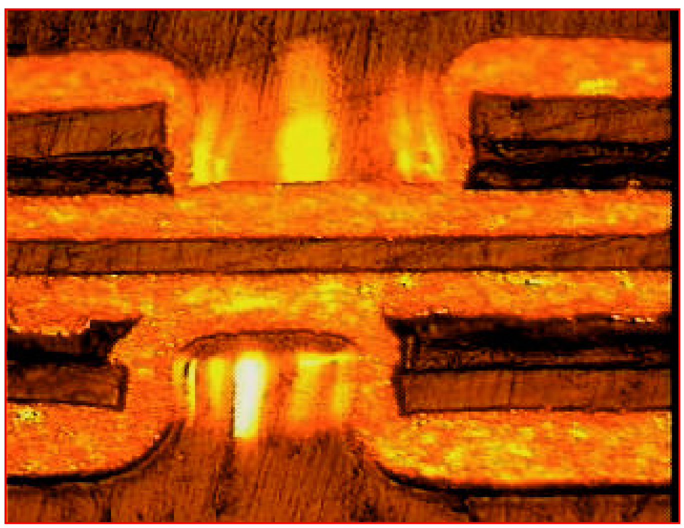


Figure 9. Cross-section of multilayer flex metallized through carbon nanoparticle dispersion.

Conclusions

After years of innovation and optimization, we have found an overall superior way to metallize FPC in a highly efficient and environmentally responsible fashion. Its performance and reliability has shown to be equivalent to that of electroless process.

References

1. “Flexible Circuits for High Density Applications” published by TechSearch International Inc in August 2000.