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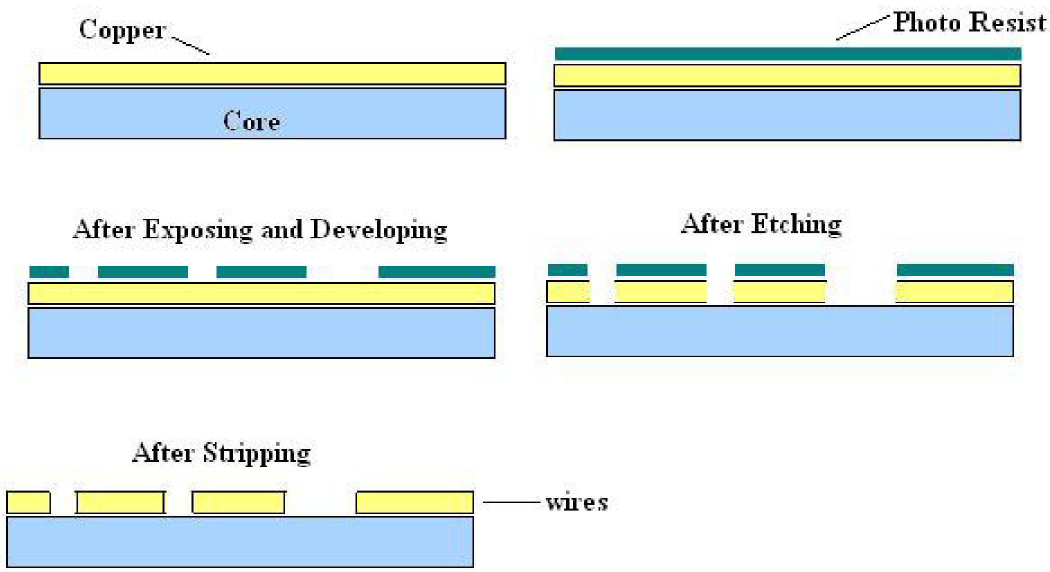
Substrate Fabrication for Printed Circuit Boards

This summer I worked in the clean room, helping the staff at PRC to improve the manufacture of substrates. Substrate fabrication starts with an insulator material coated with a thin layer of metal, usually copper, on which printed wires are designed by removing the unwanted copper. Finally, electronic components are soldered on to complete the board. The assembly of the first printed circuit board is accredited to Paul Eisler during the late 30s and early 40s. Eisler's design was used during World War II to make radios. After the introduction to consumer markets in the 1950s, the printed circuit board has become smaller and cheaper to provide consumers with more efficient products.

Most substrates are prepared by pressing a thin piece of copper foil, ranging from 10 to 100 microns in thickness, onto a blank substrate. Copper is the common material used in plating because of its ability to conduct, almost as well as gold and silver, at a cheaper cost. The copper foil is applied with a pressing machine that uses high temperature and pressure to ensure that it remains on the substrate. The next step would be to apply a photo resistant material. The purpose of this is seen later on in the process when etching or adding another layer of copper. The photo resist will allow copper on some areas of the board to remain unaltered while the areas on the board where there is no photo resist are altered. It basically acts as a shield to the parts of the copper that will remain on the board as wires. The photo resist comes in a liquid form as well as in a dry form. Since the dry version allows higher resolution, therefore allowing thinner wires, it is the common choice. However, the liquid form is more reliable in that it sticks to the surface of the board better. The machines used to apply photo resist are a laminator (for the dry film) and a spin coater (for the liquid) which essentially spins the board at high speeds while a thin layer of liquid resist is applied. The next step is to remove parts of the photo resist, using a mask, to form a pattern of wires. A mask is made of plastic film (or glass for small features) and contains the desired pattern in black and clear. The blackened areas are where no UV light can pass through, so in those areas the photo-resist will remain untouched by UV light. There are two types of photo resist known as positive and negative. In a positive photo resist, the exposed areas are destroyed while in a negative photo resist, the exposed areas are hardened. The process described assumes positive photo resist, although the procedure is actually the same if negative resist were used. An exposure tool that utilizes intense ultraviolet light is used to destroy or harden the exposed areas, depending on which type of photo resist is put on, and uses the mask as its guideline. The board is dipped in a developer solution, usually sodium carbonate, to remove and clean the board from the destroyed photo resist. The board may be baked for a couple of minutes to set the photo resist. It is then placed in a copper etch tank, which removes away any copper on the regions of the board that were exposed. Now, the copper under the unexposed photo resist, are the wires themselves. Next, the rest of the photo resist has to be removed and is done by placing the board in a strip tank, which is made of a basic solution like sodium hydroxide. This completely removes the photo resist and leaves only the copper wires on the board.

Subtractive Copper Plating Method



In the method described above, copper was etched off to form the printed wires. There is also an additive method in which copper is built up via electroless and electrolytic lines. In electroless plating, the source of copper is copper ions that are formed when copper sulfate dissolves in water. A catalyst is required to start the plating and a reducing agent such as formaldehyde is used to change copper ions into copper metal. Electrolytic plating uses the layer of copper, which is already on the board, usually as a result of electroless plating, as a cathode. When a current is passed, the copper metal at the anode loses its electrons to the copper ions in the bath (converting the ions into metal), which in turn plate onto the board. To promote even plating, the new electrolytic line has a pulse that applies the copper in a back and forth motion.

Electrolytic-Plating Process

At the Anode:

$$Cu \rightarrow Cu^{2+} + 2e^-$$

At the Cathode:

$$Cu^{2+} + 2e^- \rightarrow Cu$$

The additive process starts off with a plain, clean substrate on which copper is added through the electroless line. Photo resist is either spun on or laminated and a pattern of wires is formed with the aid of a mask and UV exposure tool. The photo resist acts again as a barrier, allowing the resist-covered areas of the pattern to remain unchanged. The board has to be developed and cleaned of destroyed photo resist. Next, the board is plated again, but this time with the electrolytic line. Lastly, the photo resist is stripped and the electroless-plated copper is flash etched.

PCBs can be single-sided, double-sided, or multilayered. A single-sided board essentially has wires on one side, a double-sided on both sides, and a multilayer board consists of several layers, separated by dielectric (the non-conductive part of the substrate) and connected together with plated through-holes and/or micro vias. Through-holes and micro vias are plated, tiny passageways that are drilled with machines that use lasers to burn through the dielectric. Multilayer boards are time consuming and require skillful effort as each layer has to be aligned precisely. My work was primarily involved in the production of single sided boards.

A significant amount of time was spent in analyzing and testing the processes involved in substrate fabrication. There are several ways to analyze the chemical make-up of the baths and has to be done regularly to ensure consistency. One method is titration, and is used often to determine the content of certain chemicals in the copper baths. Samples of the electroless bath have to be titrated to verify its pH level, copper ion concentration, and the amount of reducer before each use. Samples of the electrolytic line have to be titrated to confirm the amount of brightener (chemical that speeds up the process) and leveller (slows down the process) in the tank. There is also a device that performs flame tests and records wavelengths and their intensities to determine the ion concentration in the copper baths. To test the copper plating in the vias and through-holes, a cross-section of the sample is taken. This is done by first cutting a sample, drying it upright in a polymer mold and polishing down until the desired features can be observed. A microscope is used to take measurements and pictures of the cross-section. Before plating copper or applying photo resist, test runs are done to assess the thickness of the material that is being added. The Dectak instrument, which measures the difference in thickness between the plated and unplated regions of the board, is used to accomplish this task.

During my stay at PRC, I partook in the manufacturing and testing of the substrates. I helped in cutting, laminating/spin coating, exposing, and developing the photo resist. I learned to operate the electroless and electrolytic copper baths, the laminator and spin coater, as well as the exposure tool. This experience refreshed and helped me utilize my chemistry skills, which is useful in understanding what is actually happening when a board goes through the plating process. I also gained knowledge about basic engineering fundamentals and discovered the challenges that face engineers working in the substrate industry. This program gave me an outlook of the kinds of situations engineers must confront and what is expected of them in terms of innovation and advancement in their field.