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SUMMARY: The key today is market know-how: knowing and understanding the needs of a PCB shop and translating that into film specifications.

After World War II, when radio tubes were being replaced by semiconductors, connections moved from soldered copper wires to PCBs. It was the dawn of a new industry.

During the ‘50s and ‘60s, single-sided boards ruled the world. In the early ‘60s, double-sided boards entered the scene. A decade later the holes of these double-sided boards were plated. Then multilayer boards appeared. Holes were mechanically drilled, but when high-powered lasers became available, microvias gave birth to sequential buildup boards. It is to be expected that under the ever increasing pressure of new applications, more functionality per square centimeter and especially cheaper, higher performing PCBs will be developed.

During this early era, the cradle of the PCB was in England. Under the influence of Silicon Valley, the PCB industry moved to the U.S. In the 1980s, the rise of Japanese electronics manufacturing resulted in an important PCB industry developing under the Rising Sun. Lately, economics (labor costs) have led the PCB industry exodus to Eastern China. The United States and Europe, each with a market share below 7%, became small players. But Japan defended its 20% market share well. Today, Asia is responsible for 85% of the world’s PCB production.

Where do we go next? We see interest in mainland China, while Vietnam and India are making special efforts to acquire a piece of the pie. Additionally, Brazil and Russia may become important players.

By 1985, 6,100 companies were involved in the production of PCBs worldwide. As of 2010, the number of shops had decreased to 2,600. The PCB industry had matured into a limited number of strong companies. It is generally accepted that that figure continues to decrease.

Over time, PCB construction, production location and the professionalism of the manufacturers have changed, but the basic principles have not. After more than 50 years, one still starts with a full surface copper, adds a full surface resist, images and develops the resist, etches the copper, and strips the resist. Not the wisest approach.
From Day One, silver halide films were used in the production of PCBs. The first phototools were pencil drawings shot by reprographic cameras on reprographic films. Then, tape replaced the pencil. Blue and red tapes were used for solder and component side. The cameras and the film didn’t care.

Gerber opened a new era when it launched the Gerber language and the photoplotter. The design was created on a computer and the phototool was imaged by a vector photo plotter. A light spot, generated by a standard light bulb and shaped by apertures, travelled over the film, drawing the pattern as if it were laying down tape.

The specs of a PCB film and a reprographic film slowly began to differentiate. A PCB film was copied several times whereas a reprographic film, renamed graphic film, was copied only once to an offset printing plate. The printing plate was multi-copied. As a result, film suppliers designed PCB films with improved scratch resistance. With multilayer PCBs, the importance of a better dimensional stability became obvious. In the graphics industry, the four films (one for each printing color) had to match. All layers had to match one another, but they also had to match the drilled holes. Phototooling film 7 mils (175 micron) thick became the standard.

Vector plotters couldn’t cope with the speed needed to plot high-resolution phototools. In those days, 4,000 DPI was considered high resolution. The flatbed plotters were replaced by internal and external drum raster plotters. Afterwards, due to accuracy limitations, the internal drum raster plotter gave up. Raster plotters first were equipped with green, then blue and later red lasers. Modifying the color sensitivity of a PCB film was not hard to do. But making sure a good image was formed in nanoseconds, about a million times faster compared to a camera or a vector plotter, was more difficult.

Until the end of the 1980s, phototools were processed in Lith chemistry. The photographic quality was unsurpassed, but the stability was hard to control. This processing required constant monitoring and correction. Rapid access chemistry was far more robust, but didn’t supply the expected image quality; in particular, good line width control was a problem. By the turn of the century, hybrid chemistry offered the requested image quality, comparable to Lith, combined with the ease of rapid access.

Today a phototooling film and its relevant chemistry are real masterpieces. Only three companies worldwide are able to address all issues involved. The energy needed to generate a full black latent image in one square meter of Idealine RPF film is 8.0 mJ. That equals the energy generated by a cube of sugar (6 grams) falling from a height of 14 centimeters.

A phototooling film must serve many masters, as evidenced by Table 1.

The problem with designing a phototool is conflicting interests. One can increase the thick-

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<tr>
<th>Photographical</th>
<th>Physical and Chemical</th>
<th>Others</th>
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<tr>
<td>Low Dmin and high Dmax</td>
<td>High dimensional stability</td>
<td>Fitness for AOI</td>
</tr>
<tr>
<td>Best line sharpness and roughness</td>
<td>Trouble free loading and und</td>
<td>No impurities</td>
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<tr>
<td></td>
<td>loading in plotter</td>
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<tr>
<td>Highest resolution</td>
<td>Good vacuum behavior on</td>
<td></td>
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<td></td>
<td>plotter and printer</td>
<td>Low dust contamination</td>
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<tr>
<td>Precise line width control</td>
<td>Highest scratch resistance</td>
<td>Consistent quality</td>
</tr>
<tr>
<td>Wide exposure latitude</td>
<td>Permanent antistatic</td>
<td>Long shelf live</td>
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<tr>
<td>Wide process latitude</td>
<td>Low anisotropy</td>
<td>Compliant with legislation on ecology, health and safety</td>
</tr>
<tr>
<td>High energetic sensitivity</td>
<td>Low chemistry consumption</td>
<td>Price</td>
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Table 1: Characteristics of a silver halide film.
ness of the base material in order to improve the dimensional stability and handling, but by doing so, the $D_{\text{min}}$ goes up; the dimensional changes, even though smaller, occur more slowly, and the price goes up. One can improve the hit rate of a phototool by increasing the thickness of the anti-scratch layer(s). That works, but then the processing kinetics is slowed down, affecting the image quality, and because thicker layers absorb more water, the dimensional stability is poorer.

Another compromise to be made is the silver crystal size. In the emulsion preparation, one can control the size and shape of the silver crystal quite well. Smaller crystals have a better resolving power and thus can handle smaller lines and spaces. But, the smaller a crystal, the more light is needed to image it. Plotting at high resolutions is done with smaller spot sizes, with less energy and with faster dwell times.

After more than 100 years of development, phototool manufactures have a large arsenal of possibilities to use for any given compromise. The key today is market knowhow: knowing and understanding the needs of a PCB shop and translating that into film specifications.

Today, two types of coated film constructions are used: double-sided and single-sided. Double-sided coated films have gelatin layers on both sides. With respect to water absorption, one is compensating for the other. As a result, this type of film will not curl when the relative humidity is changing. The price paid for that is the gelatine load. More gelatin means more water absorption and thus a greater dimensional change. Single-sided coated films have gelatins on the emulsion side only. Often, these films are referred to as plastic back films. The curling of these films is acceptable when the relative humidity changes are limited. In high-end PCB shops, where temperature, relative humidity and dust level are well controlled, the curl disadvantage is by far compensated for by the better dimensional stability.

**Figure 1:** Cross-section of all layers on emulsion side.

**Figure 2:** Cross-section of emulsion layer.
A silver halide phototool is based on a 175 micron-thick polyester base. The base is double-sided-coated with two adhesion layers on each side. An adhesion layer is 200 nanometers thin. The matte particles on the emulsion side are spherical transparent plastic pearls with a diameter of 2.2 microns. They are partly embedded in the anti-stress layer. The matte particles control the vacuum build up and behavior during printing. Agfa phototooling films have two gelatin-based, anti-stress layers. The upper one contains a grease component that encapsulates possible dust particles and prevents them from damaging the image underneath. The second anti-stress layer adds robustness and acts as a barrier to prevent contamination of the silver crystals. The total anti-stress thickness is 1.5 microns. The emulsion layer is 2.5 microns thick and consists of silver halide crystals embedded in gelatin. The crystals are approximately 200 nanometers in size. A crystal contains up to one million silver halide compounds.

During imaging, the silver crystals absorb part of the light to create a latent image. In the developer, that latent image will be chemically applied to metallic silver, which is fully black. The fixer then removes the unused silver. The leftover light may generate a so-called ghost image. Therefore, an anti-halo layer is added that absorbs the leftover light. With a single-side coated film, the anti-halo layer is coated between the emulsion layer and the base. With
a double-sided coated film, the anti-halo is added to the back layer. Then, PEDOT PPS, a conductive, transparent, flexible polymer, is added to the back layer in order to give the film its permanent anti-static characteristics. Anti-static film does not attract dust particles. Dust on a phototool during imaging and processing can cause “pinholes.” During printing, dust absorbs the UV light needed to polymerize the resist.

The matte particles on the back side are spherical transparent plastics with a diameter of 4.6 microns. These matte particles control the loading and unloading in the plotter and assure the films can be separated.

Today, the PCB industry worldwide processes approximately 2.5 billion square metres of imaged or structured surface area per annum, and more than 90% of that surface is imaged using silver halide phototools (a small amount is still imaged using diazo film or by screen printing). The remaining 10% is imaged by other technologies.

The most important alternative printing technology is laser direct imaging (LDI), which offers some benefits that a film cannot, but it is cursed with some structural drawbacks. Still, LDI is a viable way to produce certain PCBs.

One of the drawbacks of LDI is the expensive optics required. Projection systems, based on digital mirror devices, do not have that drawback and are a good candidate to compete with film and LDI.
All of these technologies are additive. In other words, one starts with too much and adds some more on top of that to then take away what is not needed. The holy grail of PCB production is a reel-to-reel full additive system. Inkjet may do the job one day. Konica Minolta recently announced the KM128SNG-MB print head. The droplet volume is 1 picoliter. The diameter of the droplet in flight is 12 microns. With a good copper preparation and good control of the rheology of the ink lines and spaces, 25 microns may become possible.