Tech Talk

Fine Lines in High Yield (Part CXLIV)

Image-to-Hole Registration

Karl H. Dietz (for CircuiTree Magazine, September, 2007)

Karl Dietz is the manager at DuPont's Electronic Materials Laboratory, Research Triangle Park, NC. His responsibilities include application studies for printed circuit materials. Karl has 35 years of experience in a variety of R&D, manufacturing and quality control functions and holds a PhD. in organic chemistry from the University of Frankfurt, Germany. If you would like to participate in the exchange or if you have any questions, Karl Dietz can be reached at 919-248-5248, fax: (919) 248-5132, or via e-mail <Karl.h.dietz@usa.dupont.com>.

Several strategies are being employed in PWB fabrication to assure that metallized vias and drilled through-holes align with circuit patterns and solder connections. Recently, I talked to Dr. R. Barry Johnson, CTO of CyberAir Technologies and member of the board of directors of Innalabs Holding (Ref. 1), and I learned about an elegant, novel way to align pads to drilled holes which I'd like to share with the readers of CircuiTree. Before I do this, let's take a look at more traditional ways to register holes to circuit features. The following is a random list of registration techniques that come to mind.

Use of a diazo phototool

The UV-opaque areas of a diazo phototool are transparent to most of the visible spectrum which means an operator can visually align pads on the phototool with holes on the resist covered outerlayers or the soldermask covered board. The phototool is then taped to the board in the correct position and the procedure is repeated on the backside of the board. The transparent, dark amber-colored pattern on the yellowish background of the phototool which the operator uses to for alignment is formed when a diazonium salt is exposed to ammonia vapors and links to couplers that are present in the phototool. When the phototool is plotted, the diazonium salt decomposes in areas that are exposed to UV-radiation, leaving only the yellow background coloration. The dark amber color that is formed during development is actually not the UV-opaque material that gives the phototool its functionality. Another diazo "dye" that absorbs in the UV region is developed in the non-exposure areas, invisible to the eye.

Automatic exposure machines

Automatic exposure machines typically make use of CCD cameras to achieve pattern-to-hole alignment. Safe light shines from the backside through the photoresist covered registration/tooling holes and is detected by the CCD cameras at the front-side. The board position is then adjusted to be in the right position when the phototool makes contact.

Hinged glass frame fixtures

Hinged glass frame fixtures use pins to position the board. Phototools with pre-punched registration holes are placed on top and bottom surfaces of the board, using the same pins. Vacuum is then drawn between the phototools and the supporting glass frames through vacuum groove channels in the glass. After the phototools are positioned securely on the glass by the vacuum, the photools are taped in the correct position.

Post-etch punch

A popular method for image-to-hole registration for innerlayers involves the use of a so called post-etch punch. Front and backside circuitry need to be only "side-to-side" (or front to back) registered. After lamination, exposure, development and etch, the board enters the post-etch punch, often in-line with the DES line. CCD cameras then locate copper fiducials, and adjust the position of the board before punching tooling holes. This method has the added advantage that any punching debris is formed after the dirt sensitive image transfer is complete.

Image scaling in LDI (laser direct imaging)
One very useful feature of LDI is its ability to scale the digital image for best fit to a panel whose drilled hole pattern has shifted due to dimensional changes of the board during processing. The LDI calculates "best fit" of the image and adjusts dimensions before plotting. Some LDI systems can scale locally for best fit to sub-segments of the board area. Scaling in x and y direction can be independent, i.e. anisotropic.

Step and repeat imagers

Step and repeat imagers can adjust the focus of the image within certain limits to adjust "one-up" exposure dimensions on "multiple-up" images for best fit, using CCD cameras to locate reference holes.

Use of X-ray drills

To align the NC drill pattern for plated through-holes to buried innerlayer features, an X-ray drill can be used. The X-rays "see" the innerlayer features and then drill reference holes which serve as tooling holes for positioning the board in the NC drill for drilling the through-holes.

Self-aligning via-to-circuit technologies

There are several techniques, none of which are mainstream PWB manufacturing technologies yet, that are inherently hole-to-circuit self-aligning. An example is the formation of circuit grooves and via holes in a single laser ablation step. Metallization then follows, using the dual-damascene technology that is practiced in IC fabrication. Another example is the imprint technology where a tool plate embosses circuit grooves and holes into a suitable dielectric substrate.

Innalab's 3Z Technology

This technology was first presented at the PCB Design Conference West, 2007. It makes use of the oxygen inhibition of a radical chain polymerization by oxygen. The initiation of acrylate polymerization by radicals is a complex reaction sequence (Ref. 2). It typically starts with the absorption of a photon by a "sensitizer" molecule (see Fig. 1.). The photo-excited sensitizer can then transmit its energy to a photoinitiator, which forms a radical, and starts a chain polymerization. However, there are competing reactions capable of consuming the energy originally trapped by the sensitizer: The sensitizer's excited state can decay to the ground state by emitting radiation. Oxygen or small amounts of organic inhibitors, deliberately added to the resist formulation to stabilize it against premature polymerization, may react with excited state sensitizers, initiators, or radicals to form inactive products which will not lead to the polymerization of acrylate monomers. Finally, the recombination of two radicals or the scavenging of radicals can prematurely terminate the chain polymerization by oxygen.

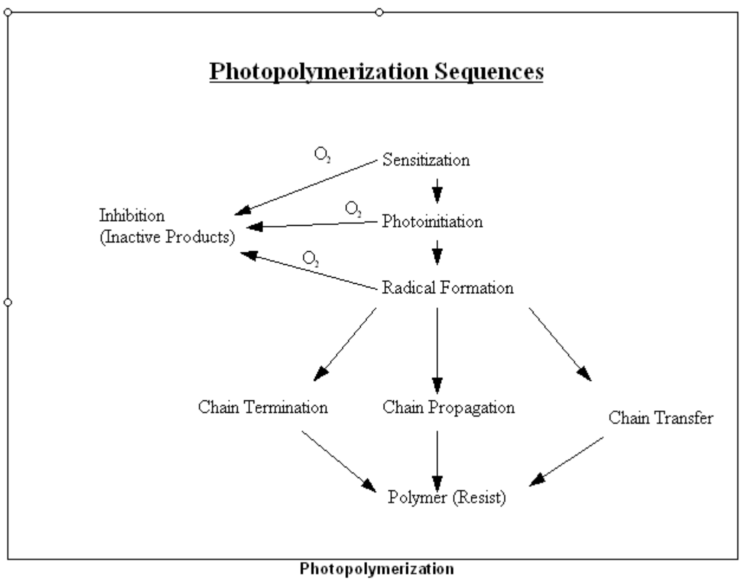

Figure 1: Reactions in Chain Polymerization

Radical scavenging reactions serve a very useful purpose by creating a "threshold" against premature polymerization or polymerization in non-exposure areas (see Fig. 1.): low levels of radiation yield only few excited state sensitizers and initiators which react with oxygen and other inhibitors to form inactive products. Chain polymerization only sets in at higher levels of exposure energy, after the inhibitor molecules have been consumed. Thus, photoresists have a reasonable shelf life with regard to premature thermal polymerization and in the presence of low level radiation. Also, low levels of unwanted, scattered UV radiation in non-exposure areas of the resist may not cause polymerization. Therefore, the polymerization threshold formed by inhibitor molecules "re-digitizes" a blurred, scattered image. It is desirable to keep any remaining transition zone between non-polymerized and fully polymerized resist as small as possible to achieve the best contrast and definition of the developed resist image.

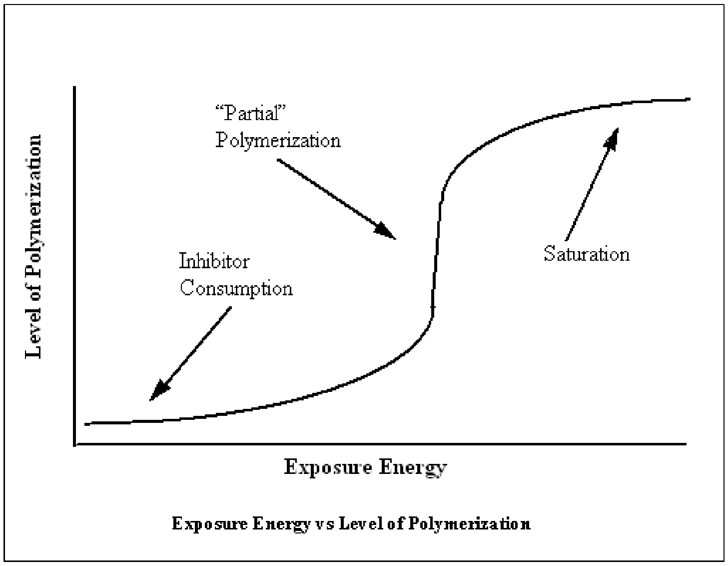

Figure 2: Exposure Energy – Level of Polymerization Relationship

Since oxygen is a potent radical scavenger, it will first react with the radicals formed by UV exposure. This will continue until all the oxygen that is dissolved in the resist is consumed. Only then will the chain polymerization begin. The polyester coversheet that covers the resist during exposure serves as a barrier to oxygen replenishment during exposure. Without it, higher exposure doses will be required to overcome the additional inhibition due to the re-supply of fresh oxygen. A special situation exists when the photoresist tents over a through-hole or blind via: the air trapped in the hole provides additional oxygen that can replenish the oxygen that is dissolved in the resist, given enough time for diffusion. This diffusion has been recognized as an issue in the tent & etch process, so that a slightly higher exposure dose in tent & etch applications is recommended than for other applications to assure good polymerization of the tent. The 3Z Technology takes advantage of the trapped oxygen in the hole in the following way. With suitable photoresists of a certain photosensitivity one can expose features on the board surface without polymerizing the resist tent over the hole and the adjacent halo of resist around the hole. If one waits some time to allow the oxygen in the hole to diffuse into the resist, then a second exposure will complete the polymerization of the surface features without causing polymerization of the resist tent over the hole and around the hole rim. Thus, a 3Z phototool for pattern plate will have lines but the lines don't end in pads because no pads are needed to block the light over and around the hole (Fig. 3). As a result, the developed resist pattern for the annular ring is always perfectly self-aligned with the hole, even if the line is not. Figure 4 shows that for a given degree of line mis-registration, the 3Z Technology may result in no "hole break-out" whereas conventional exposure may cause hole break-out.

Another application is the formation of very high aspect ratio resist structures through double or triple lamination, exposure, and development of photoresist over a first exposed and developed resist layer. The developed openings in the first resist layer provide the trapped oxygen to inhibit polymerization of the second and third layers in the same position.

Acknowledgment

Information provided by Barry Johnson and Michael Ellenby is gratefully acknowledged (contact information: Michael Ellenby, SVP Sales and Marketing, at michael.ellenby@cyberair.net or on 480 633 2612 x226)

References

1. Innalabs Holding, Inc. 11654 Plaza America Drive, #218, Reston, VA 20190 (www.innalabs.com)
2. Dry Film Photoresist Processing Technology, Karl H. Dietz, Electrochemical Publications Ltd., 2001 (ISBN 0 901150 39 8)

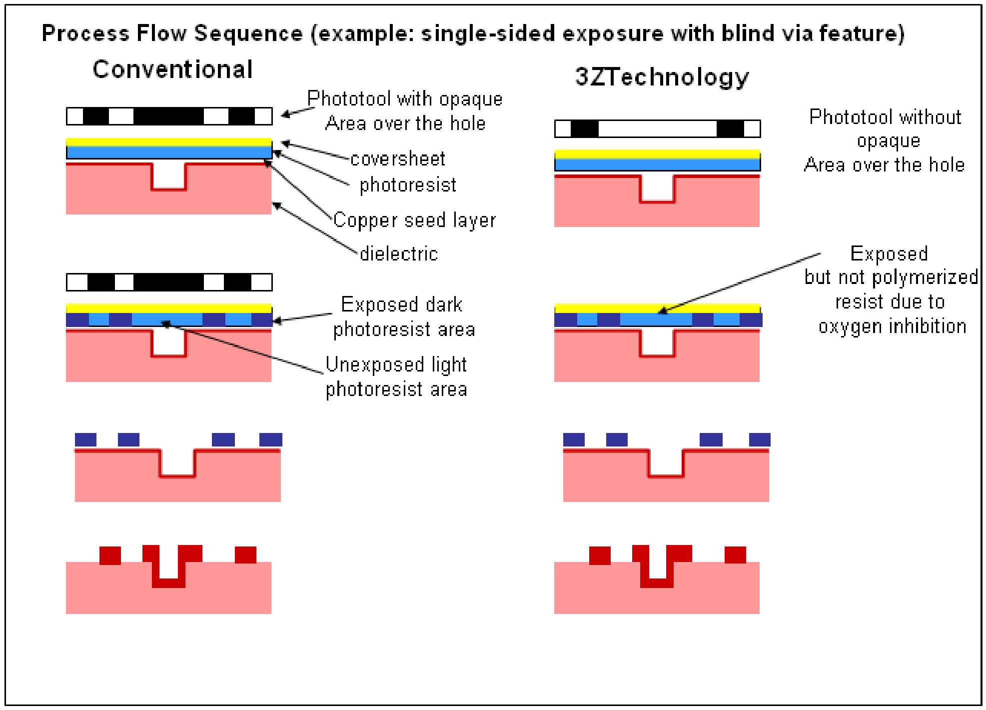

Figure 3: Comparison of 3Z Exposure with Conventional Exposure

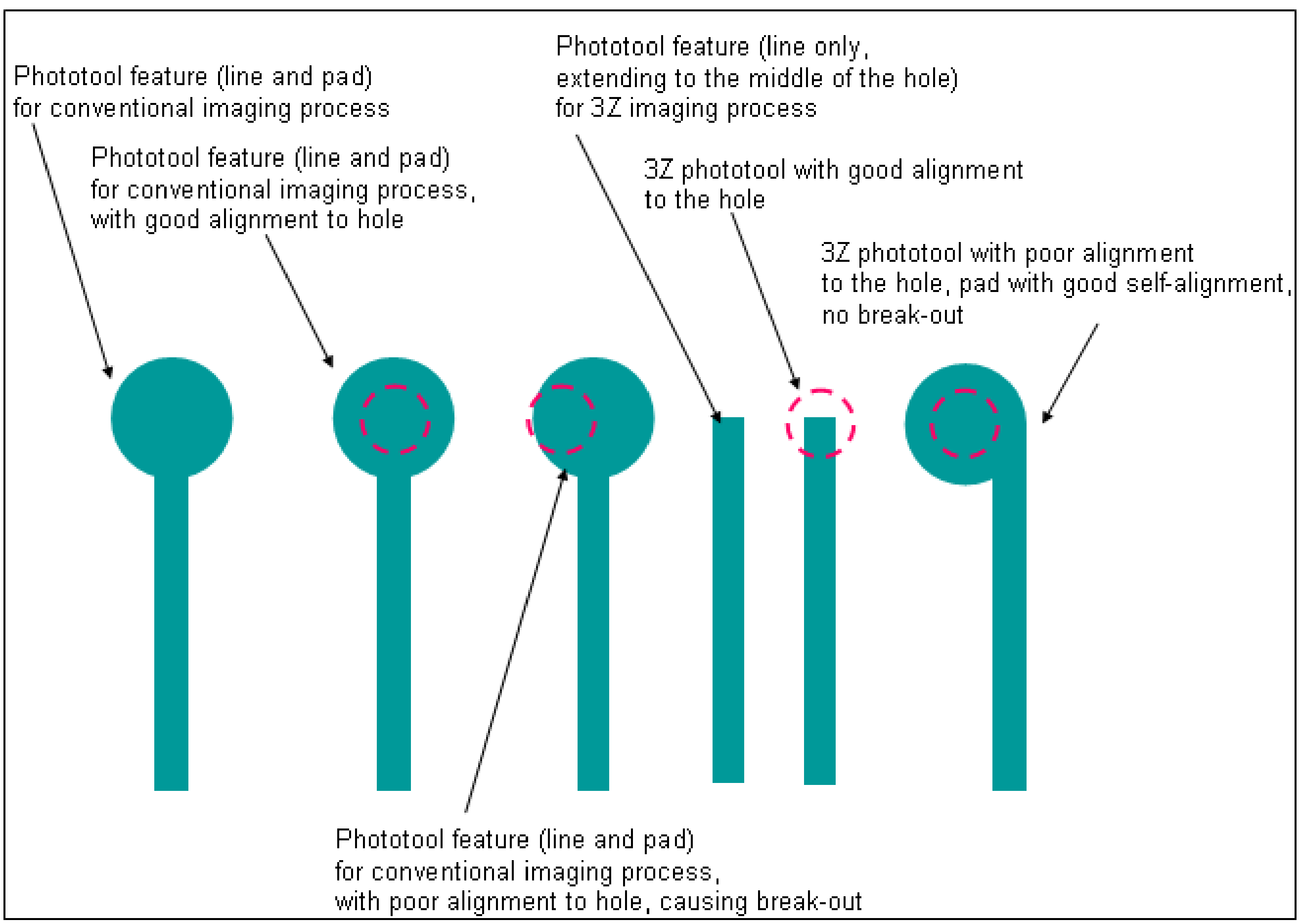

Figure 4: Illustration of Mis-registration Effect with Conventional Phototool and 3Z- Phototool