



e-Print & Printable Electronics

Applying Cylinder Screen Printing to Printed Electronics

— Pursuing Printing that Does Not Stretch the Screen —

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Introduction

Photolithography is widely known as a patterning technology used to produce printed circuit boards and electronic devices. This is a type of method, however, which removes unnecessary material from a substrate using a sequence of processes—film forming, resist coating, thermal treatment, exposure, development, etching, and resist removal.

By repeating this sequence several times, the method forms the wiring or electronic device only after many processes. As a result, the process load is high and the ratio of material discarded to that remaining on the circuit board is extremely high for the resulting pattern, both of which are problematic in terms of their large environmental impact.

Expectations on Printing Technology

In contrast to photolithography, printing methods pattern the product using just two process—transfer and thermal treatment; in other words, it layers the material on the necessary areas only. Compared to photolithography, the number of process and environmental impact is also low. Moreover, printing methods have been gaining attention as a technology for printed electronics that can form large area electronic devices at low cost.

The basic quality requirements for patterning that allows for these types of devices are:

1. Electronic circuitry and wiring requirements:
 - » Electrical properties
 - » Adhesion with the substrate
2. High grade, uniform product manufacturing requirements:
 - » Definition

- » Configuration and film thickness in-plane uniformity
 - » Repeated reproducibility
 - » Continuous printability
3. Multi-layer patterning of different configurations and materials requirements:
 - » Dimensional precision (low distortion)
 - » Alignment precision

Issues with Screen Printing

Until now, standard screen printing technology used in the electronics field has mainly been employed to print on rigid substrates or small components, such as printed circuit boards, glass substrates, and silicon substrates. The printing method called the flatbed type, shown in Figure 1, is often used in these cases.

Screen printing uses a thin screen (plate) material, such as a mesh, that has had holes opened in the lined sections with a photosensitive emulsion. A squeegee is used to push the ink or paste from the surface of one side of the screen through to the other side; the ink or paste then adheres to the substrate. The time that the screen and the substrate are in contact affects the volume of ink or paste transferred, but since the paste leaks into the space between the screen and the substrate, the contact time also affects the definition. Therefore, with flatbed type screen printing, a gap (clearance)

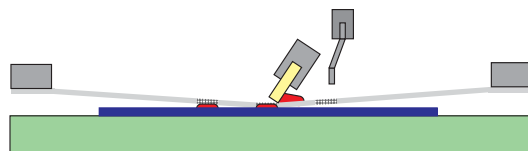


Figure 1 Flatbed Type Screen Printing

of between 2-10mm is set between the substrate surface and the screen and the squeegee pressed vertically down on the screen as it is swept over the screen. After the paste has adhered to the substrate, the screen lifts off the substrate using the elasticity of the screen itself (screen separation), which shortens the contact time and allows for continuous printing that reduces bleeding.

On the other hand, since the screen is stretched in the vertical direction, the screen distorts, which lowers the dimensional precision; the larger the screen size, the more prominent this distortion. In addition, as shown in Figure 2(a) and Figure 2(b), the difference in reaction force received by the screen as well as the difference in the screen separation angle between the start of the printing and end of the printing and between the center and edges of the squeegee are causes of in-plane unevenness.

For example, screen printing is used to print silver paste to form electrodes of around 100µm for touch panels used in tablet PCs, a recently popular item. Moreover, there have been attempts at finer wiring of 50-80µm, but in order to reduce the deterioration of the definition caused by paste spreading immediately after transfer that comes with finer lines, the viscosity is raised to over 100 Pa s, or to a level that is similar to the consistency of peanut butter.

In this case, the paste functions as a kind of pressure sensitive adhesive (PSA) between the screen and the substrate, so that the screen separation time and angle differ in-plane. As a result, this difference often causes configuration variation, such as uneven film thickness and bleeding. Therefore, increasing the clearance gap and increasing the screen separation angle achieves clearer definition, but since

these changes narrow the process window, they risk affecting the yield ratio and causing plastic deformation of the screen. In addition, a stainless steel screen having a print resistance of several tens of thousands of shots must be replaced after about one thousand shots, so these are all factors affecting productivity and production cost.

In this way, since the flatbed type uses an elastic screen and the squeegee used by the method stretches the screen in the vertical direction, there is a conflicting, trade-off relationship among the basic printing quality properties, such as definition, dimensional precision, in-plane uniformity, and printing resistance in terms of the clearance (Fig. 3).

At the actual printing plant, the screen, paste, and printing conditions are calibrated in an attempt to find a compromise that realizes both quality and productivity. This know-how is what gives a company competitiveness and sets it apart from its competitors.

On the other hand, as with standard industrial products, it is necessary to eliminate such trade-offs as much as possible in the pursuit of mass produced quality at low cost.

Cylinder Press

Flatbed type screen printing can be used by anyone for manual printing as long as the operator has a flat table and a screen. Since screen printing is versatile, it is widely used, from the point of experimental research and prototype development to mass production.

In contrast, when screen printing technology is applied to flexible substrates, cylinder type screen printing machines that can print at high speeds even on large size substrates are widely used for industrial products. For example, the high level of productivity of cylinder types is used for mass produced products such as membrane switches, seat heaters, seating sensors, blood sugar level sensors, film antennas, home appliance control panels, mobile phone decoration, LCD backlight diffusion sheets, 3D micro-lenses, dot spacers,

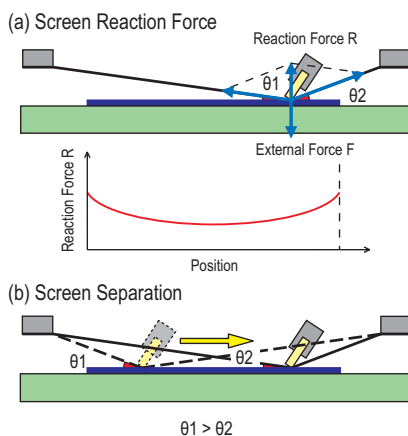


Figure 2 Screen Reaction Force and Screen Separation

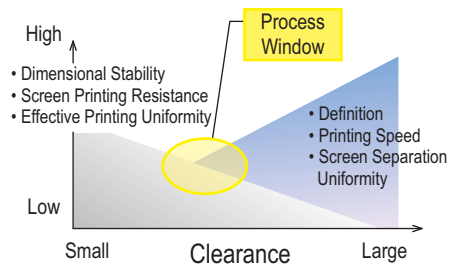


Figure 3 Flatbed Type Dilemma

transfer sheets, stickers, dummy cans, speedometers, and cash cards.

In contrast to the squeegee being run over the surface of the flat table in flatbed type screen printing, the flexible substrate is pinned to the curved surface of a cylinder, as shown in Figure 4, and the squeegee pressed against the screen from above. The approach prints by rotating the cylinder to transport the substrate at the same time the screen is simultaneously driven in the horizontal direction.

While in the flatbed method the substrate is handled by alternately printing and exchanging the substrate, in the cylinder method, since the printing is conducted simultaneously with the substrate being paid out, the following substrate is transported close to the cylinder and preparatory work, such as position setting, can be done at the same time as the printing. In this way, time loss from substrate handling is reduced. In addition, during printing, the substrate film is pinned to the impression cylinder, so the paste is transferred to a bent substrate. Since the screen separation system mechanically removes the substrate from the screen at a constant, fixed angle immediately after transfer, it is possible to achieve a uniform printing quality from the start of printing to the end of printing; at the same time, the speed of the squeegee can be increased. This combination allows the operator to pursue optimal printing conditions.

In this way, cylinder type screen printing machines meet the productivity and large area requirements necessary for printed electronics.

Screen Printing that Does not Stretch the Screen

In conventional screen printing methods, regardless of whether one is using a cylinder type or flatbed type machine, a clearance gap is set, which causes the screen to stretch during printing.

In contrast, the cylinder type has a basic structure that

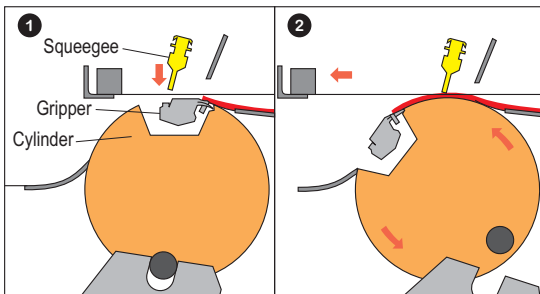


Figure 4 Cylinder Type Cross-sectional Model

allows it to put the bent substrate surface in contact with the screen along a single straight line without deforming the screen in the vertical direction. In this case, the screen does not need to be flexible, allowing for printing that does not stretch the screen, which is unique to the cylinder method whose ideal screen would be one that is hard and does not deform (Fig. 5).

Sakurai Graphic Systems Corporation is taking advantage of this characteristic in pursuit of high precision screen printing technology demanded for printed electronics. The following introduces some of the printing results using the fully automated MS80SD Cylinder Press (Photo 1).

The following four points are essential to realizing high precision printing with printing that does not stretch the screen.

Low Clearance Function

The cylinder in this system uses a stop, called a gripper, which securely holds the front edge of the substrate and pins it to the cylinder. Since the gripper sticks up above the cylinder's surface slightly, a gap between the screen and the cylinder is typically set apart by a few millimeters so that the screen and the gripper do not interfere with each other.

After the gripper has grabbed the substrate, the cylinder is rotated slightly to a position where the gripper will not interfere with the screen. Once the gripper and screen are separated, the screen is lowered to a point where the clearance gap is as close to zero as possible.

Low Warping, High Elasticity Screen

Even if the clearance is reduced, if the screen is flexible and stretches easily, as with standard synthetic fiber meshes, the drag force that comes with the sweeping of the squeegee causes the screen to bend in the parallel direction to the screen surface and become distorted. Therefore, in order to reduce this nonlinear distortion, screen making is adjusted within the existing range of screen making technology to produce a screen that has an elastic modulus that is as high as possible to produce a screen that is hard and difficult to distort.



Photo 1 Exterior Photo of MS-80SD

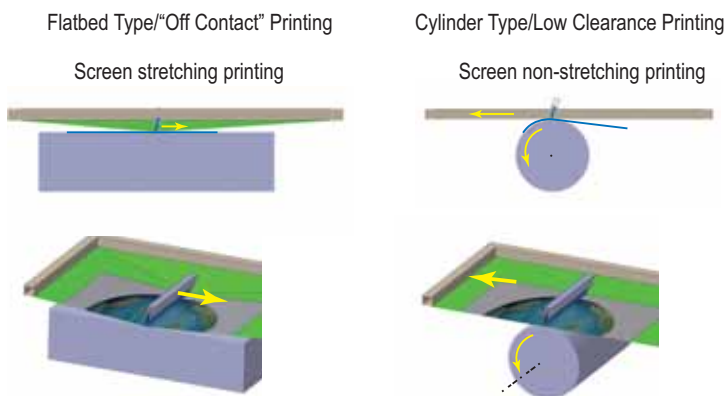


Figure 5 Low Clearance Printing

Printing Elongation Correction Function

Even when using a strengthened screen, distortion in the sweeping direction of the squeegee continues to be a problem. The screen elongates in the direction of the screen surface immediately after the start of the sweeping of the squeegee, but as the squeegee approaches the end of the screen, the screen contracts. With the MS-SD series, the cylinder and the screen frame are each driven by an independent servo, so a “printing elongation correction function” is provided by increasing or decreasing the speed of the rotational phase of the cylinder slightly in relation to the transport speed of the screen frame. Using this function, it is possible to correct for the elongated or contracted distortion in the printing direction.

Camera Alignment

A side-view type miniature image processing camera and a suction stage for positioning the substrate are attached above the delivery board (Photo 2). The camera reads the mark on the substrate immediately before the cylinder gripper grabs the substrate, and by rapidly and accurately aligning the position



Photo 2 MS-80SD Camera Alignment Section

and angle of the substrate, the system allows for high precision, superimposed printing.

Printing Examples

We printed a line definition test chart in a 300mm² area using an 880mm² frame with a stainless steel 500 mesh combination screen made to low distortion, high elasticity specifications. The printing used TOYOCEM CO., LTD. “RAFS058” silver paste for printing line widths of between 70-100µm.

Figure 6 is an image of L/S=50/50µm lines on porous film and L/S=70/70µm lines on uncoated PET. The clearance gap was set to 0mm, and the squeegee was swept across the substrate from the bottom of the photo to the top of the photo. With the flatbed type, the lines bled when the clearance was reduced and we were not able to produce the appropriate definition; with the cylinder type we were able to form fine patterning as there was no bleeding in the lines in the direction the squeegee was swept, the lines perpendicular to the sweeping and those at other angles, the corner sections, and the crossings of thin lines and thick lines.

Figure 7 is an image of a 1mm diameter circle printed on uncoated PET with the same silver paste and screen described above. The figure also shows the in-plane diameter and circularity distribution of circles printed at 49 locations with 50mm pitches in a 300mm² area. When the circularity has a value of zero, the circle is perfectly round and higher values express an increasing distortion from circularity in some of the circles. If there are gaps, scratches, or bleeding, this value

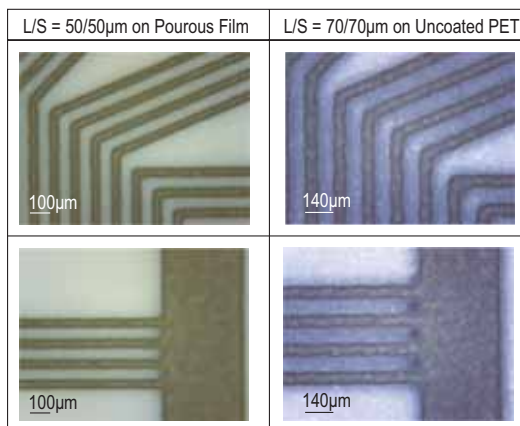
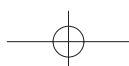


Photo 6 Silver Wiring



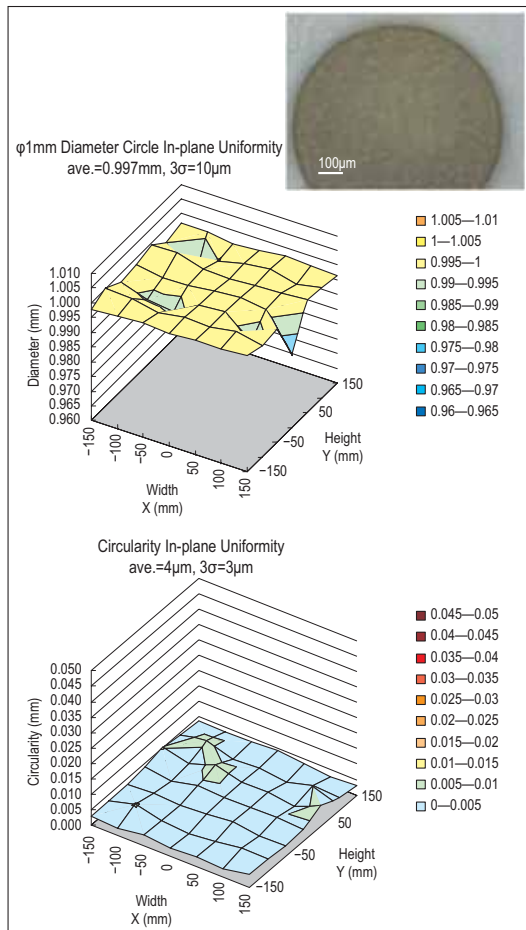


Photo 7 In-plane Uniformity

increases. While the squeegee was swept from the lower left hand section to the upper right hand section of the figure, we realized a uniform pattern that has no specific trend in circularity from the start of printing to the end of printing or in the length direction of the squeegee; the in-plane uniformity for the diameter had an average of 997μm with a 3σ error of 10μm and the circularity showed an average of 4μm with a 3σ error of 3μm.

Figure 8 shows the dimensional change in the squeegee sweeping direction caused by the printing elongation correction. This example uses a stainless steel 360 mesh combination screen and JUJO CHEMICAL CO., LTD. "RC-SL6108" color UV ink. The nonlinear elongation and contraction distortion seen prior to correction is reduced to within ±10μm when printing using the printing elongation correction function.

Figure 9 is the printing dimensional precision of a grid with

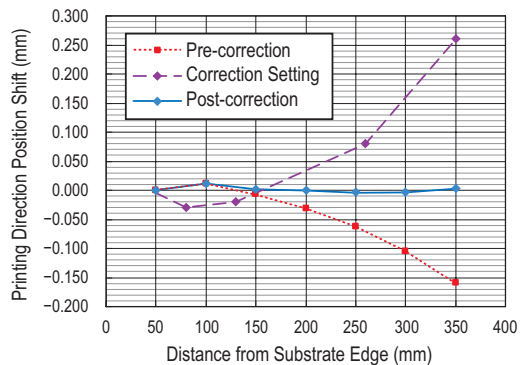


Photo 8 Printing Elongation Correction

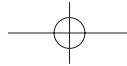
a 50mm pitch using the same ink and screen as the previous example. The approach maintains linearity over an area of W200mm x L250mm, about the same size as an A4 piece of paper. In addition to the printing elongation correction, we achieved a shift value of ±10μm from the reference frame in both the longitudinal and transverse direction. Based on these results, we have confirmed the possibility of eliminating the trade-off dilemma among the printing properties that are related to the clearance gap by using the cylinder press.

Applications

For the manufacturing industry, which has been subject to severe cost and added-value competition, there is no need to explain the value that a wider process window and production technologies holding the potential for production improvement can provide.

Going forward, we will optimize the specifications of screen making and the pastes that take advantage of the strengths of the cylinder press structure, as well as the printing conditions. In doing so, we believe we can improve the printing speed, in-plane uniformity, dimensional precision, and printing resistance of the screen to improve the yield and productivity in product fields that require high-definition and high precision.

Through these improvements, we anticipate that this technology will be used for existing electronics applications such as touch panel electrode wiring, laminated ceramic components, multi-layer thick film components, flexible printed circuits (FPC), anisotropically-conductive connectors, large size touch panel auxiliary electrodes, electromagnetic shields, micro electro mechanical systems (MEMS), and pressure sensor sheets, as well as for new applications such as MLCC (multilayer chip type ceramic capacitors) type solid-state Lithium-ion batteries, paper batteries, speakers, high-functional thick film circuitry components, dye-sensitized solar cells,



electronic paper, power feed/transmission sheets, and OLED lighting/displays.

Moreover, this method is also suited to industrial graphic printing for high level designs, such as those used to decorate the panels of mobile phone handsets and gradation expression.

Future Direction

We foresee that the development of printed electronics technologies will create an entirely new market for large scale, flexible, inexpensive electronics products. Although some of these products have already been commercialized, countries around the world continue to compete to increase the speed of development for materials and applications, and have established industry groups and large-scale projects.

Among the different developments, there is much expectation on printed electronics as the fundamental technology behind ambient electronics, electronics that build in the input/output function on a mass scale and across a wide variety of devices. These devices will exist in structures that already form the environment around us, as well as power generation, power storage, lighting, and energy reduction in the energy field and in the light, thin miniaturized mobile devices

W200 × L250mm Shift Value ±10µm
Position Shift Degree: 50µm/div

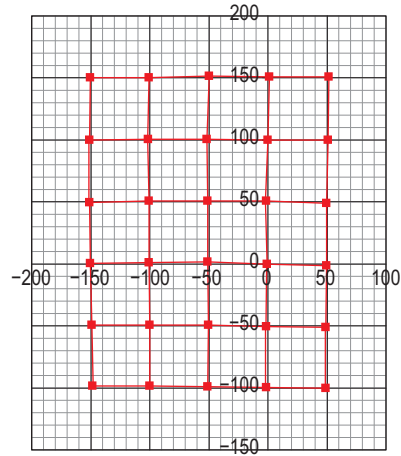


Photo 9 Dimensional Precision

that form the core of the ubiquitous society.

Sakurai Graphic Systems is expanding the application potential of screen printing technology and working tirelessly for the development of printed electronics in hopes of broadly contributing to the future of society and the Earth.

