Quality improvement to the spinless coating process of touch panel with Taguchi methods

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This study applied the Taguchi method to determine the optimal process parameters of the spinless coating for touch panels, and used a fishbone diagram to determine the factors influencing quality characteristics. Factors were then selected according to prior experience, and an appropriate orthogonal array was created according to the selected factors before the experiment. The results indicated that photoresist is the critical material in the optical lithography imaging technology of the touch panel process, which is uniformly coated by a spinless coater onto a glass substrate according to the designed circuit pattern. It is formed after the exposure, development and etching processes. Finally, as coating parameters significantly influence film thickness quality, the experimental data record is analyzed to determine the optimal process parameters, and thus, reduce the probability of defective products and repairs. Improved coating parameters render photoresist film thickness uniform to within 3%, and control the long-term level of product obsolescence below 0.2%, thus, reducing touch-screen production costs.

Keywords: Taguchi method, Touch panels, Photoresist, Coating, Film

The touch panel process contains a preceding stage and a post stage. The preceding stage is touch sensor production, where multilayer coatings, lithography, and etching screen printing processes, are carried out for ITO conductive glass or film according to customer requirements. Different lithographic masks are required for each cycle, where lines are delineated on the conductive glass or conductive film, and the required circuit pattern is exposed. The post stage is a touch module with a touch sensor cut into an appropriate size, and is laminated with IC, FPC, and a cover glass for testing. Finally, the touch sensor module is laminated with the LCD module (LCM) according to customer requirements.

Thin Film Processing

Generally, there is a water washing process prior to the thin film process, which cleans oil stains, dust fall, and contaminants off the glass surface, and leaves no drop marks or other traces on the glass surface. If there is oil stain or contaminant on the glass surface, the film cannot be firmly attached, leaving uncoated holes in the coating layer, generally called pinholes. If there are drop marks or other residual stains on the glass surface, there will be white spots formed on the coating layer. The coating process is conducted inside a vacuum chamber, where high energy particles impact the target material. The molecules or atoms are impacted out of the target, hit the substrate, and accumulate to form a film.

Photo process

The photo process consists of a photoresist coating, exposure and development processes. First, the coated glass substrate is coated with a layer of photoresist, and is exposed under a mask. Finally, development is conducted to remove unwanted patterns on the photoresist layer.

The photoresist coating process uniformly coats photosensitive photoresist onto the glass substrate. The forms of coating machines have developed from the earliest roller coating and spin coaters into spinless and spin coaters and spinless (or non-spin) coaters. This study aims at the optimization of coating parameters of the spinless coater, thus, effectively reducing photoresist costs, maintaining the uniformity of photoresist thickness, and increasing yield.

The process of photoresist coating means to uniformly coat a layer of photoresist with photobehavior on a glass surface. Photoresist constituents include resin, a photo active compound (PAC), and a solvent. Photoresist has a chemical reaction when irradiated by
the light energy of a UV Lamp, the optical pattern on
the mask is transferred to the glass surface by a
function similar to sensitizer on a negative film. The
spinless coater uses a fluted metal scraper and air
pressure to pour photoresist, which is uniformly
coated on the glass substrate surface when the scraper
is moving, and the coating area is determined as per
design. Film thickness varies with product features
and photoresist. The motion of the spinless coater is
as shown in Fig. 1.

The exposure process creates the required pattern on
the mask, and then the UV Lamp inside the exposure
machine irradiates the photoresist through the mask.7
The development process removes, by spray, any
unbonded photoresist after exposure. In the process of
development, developer concentration, provided speed,
and temperature will influence development quality.
When the developer is insufficient or the speed is too
high, there will be underdevelopment and residual
photoresist; on the contrary, overdevelopment washes
off unexposed photoresist, resulting in abnormal
products that require rework or rejection. The
developing stage must match the parameter factors of
the preceding process, and defectives in the
development process may be resulted from the
preceding process factors, rendering it difficult to
define which stage defectives are resulted from.
Therefore, regarding defectives which occur when the
development of a semi-finished product is complete, it
is necessary to give overall consideration to whether
the parameters of the entire process are applicable.

**ETCH process**

The ETCH process removes any coating material
not protected by the photoresist after the development
process. The strip process uses a stripping solution to
remove the photoresist covering the pattern, while
protecting the coating material after etch process, and
mainly uses an organic solution to implement
structural damage to the photoresist.

**Screen printing process**

The screen printer is equipped with a scraper, a
covering ink blade, a halftone screen and a screen
frame. The glass is placed in the screen frame prior to
automatic execution of the following settings. The
printing plate is made of a fiber fabric. The fabric
layout reserves pictographic letter shaped gaps for
glass during plate making, while the remaining part of
the layout is filled with colloid. The ink is pressed and
pushed by the scraper during printing, which passes
through any gaps, leaving the required patterns on the
glass surface.8

Fragments often occur in the photoresist coating
production line of touch panels (glass substrate size is
7500 × 7600 mm). Each time a fragment occurs, the
products are rejected, and the chips of glass
contaminate the production line and influence yield.
In order to remedy this problem, the fragments are
inferred to be resulted from poor linearity of the glass
plate side guide pulley, excessive brush pressure, or
too tight glass up pressing wheels. The following
improvement measures are taken to remedy this
problem: (i) The pressure level of the upper brush is
reduced from 1.5 mm to 0.8 mm, thus, reducing brush
contact on the substrate, stress on the glass substrate,
and glass rupture angle fragments, and (ii) The
linearity of the side guide pulley of the glass substrate
delivery roller is adjusted in order to avoid the glass
impacting the side guide pulley when conveying
product fragments.

Brush pressure level is an important process
parameter of the washing machine; in order to remedy
the problem of fragments, brush pressure is reduced,
and the problem of fragments is solved; however,
yield becomes worse accordingly. This study applied
the Taguchi method to determine the optimum
process conditions, thus, avoiding adjustment of brush
pressure, which influences yield, and gives equal
attention to fragments and yield. After photoresist
coating, a thickness tester and an automated optical
inspection machine were used to detect film thickness
value and the number of defects in the photoresist
film surface, in order to determine the influence of
various conditions of the Taguchi experiment on
quality.

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Fig. 1—Schematic diagram of spinless coater and the coating process of touch panels
Taguchi Methods and Parameter Designs

This study used Taguchi orthogonal arrays to configure experiments, thus, effectively reducing the number of experiments, and the orthogonal array was put into an external matrix to consider the influence of external disturbance on the overall system. Signal to noise ratio was used to determine the optimal parameter combination and cope with external disturbance for robustness.

For examples, the $L_8(2^7)$ orthogonal array is obtained by the following steps: (i) The $L_8(2^7)$ orthogonal array has eight experiments. In the first line, $8÷2=4$, where high level (represented by 2) and low level (represented by 1) are half and half, namely, the repeat number of each level is 4, arranged from low level to high level, (ii) In the second line, the repeat number of each level is 2, arranged from low level to high level, (iii) When the first two factors are configured, the interaction between the two factors shall be considered. Therefore, components AxB shall be configured in the third line, and the level of configuration depends on the product of components A and B. It is 1 if the level is the same, otherwise it is 2, (iv) A new factor is configured, the occurrence of each level is one 1, followed by one 2, and (v) As the factors configured in step (iv) are interactive with the first two factors, the interaction shall also be considered, i.e., AxC, BxC and AxBxC, where the level of configuration method is the same as step (iii).

First, a characteristic diagram of photoresist coating defects is created, where all factors influencing quality are listed, and there are five aspects, including machine, personnel, environment, materials, and specifications. The factors of implementation include: (i) IR heating temperature; (ii) electrical conductivity of degreasing fluid; (iii) brush pressure; (iv) number of degreasing fluid changing slotted vanes; (v) high pressure water wash flow; (vi) drying air knife CDA pressure; (vii) target film thickness; and (viii) coating speed. There are eight parameter factors, including one two-level factor and seven three-level factors. The factor level settings based on control factors are as shown in Table 1.

The eight parameter factors are briefly described, as: (i) Factor A: IR (infrared) oven drying section operating temperature, generally the process conditions include 100~120°C and 200~220°C (ii) Factor B: electrical conductivity of abluent (TFD-7) for glass cleaning machine, generally the process condition is 8.9~10.5 ms/cm, thus, the condition is set as 9.0, 9.5 and 10.5 ms/cm, (iii) Factor C: brush pressure of glass cleaning machine, three kinds of down pressures are set as experimental conditions, (iv) Factor D: the glass cleaning machine changes the abluent according to the number of cleaned plates, the condition is set as 500, 750, and 1000 plates, (v) Factor E: the flow rate value for high pressure micro jet of glass cleaning machine, the condition is set as 80, 90, and 100 L/min, (vi) Factor F: the blowing volume pressure value of air knife of glass cleaning machine for blowing substrate dry, the condition is set as 0.65, 0.85 and 0.95 kg/cm², (vii) Factor G: target film thickness, the wet-film thickness to be coated is set as 8.5, 9, and 9.3 µm, and (viii) Factor H: the time spent on reaching the required injection velocity since the startup of the SYP syringe, it is 2700, 2800, and 3000 ms at present.

According to the selected conditions, there are one two-level factors and seven three-level factors. Therefore, the minimum degree of freedom must be 15(7x2+1x1), and the $L_{18}$ orthogonal array is used for experimentation. The power of factor IR is two-level, thus, Factor A is allocated to the first line. The remaining seven controllable factors are three-level, thus, Factors B to H are allocated to lines 2-8, respectively. There are 18 kinds required, according to different experimental conditions.

Seven pieces are tested under each group of conditions, recorded in P1 to P7. First, the average

<table>
<thead>
<tr>
<th>Control factor</th>
<th>Item</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IR heating temperature</td>
<td>100~110°C</td>
<td>200~220°C</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Electrical conductivity of degreasing fluid</td>
<td>8.5 ms/cm</td>
<td>9.5 ms/cm</td>
<td>10.5 ms/cm</td>
</tr>
<tr>
<td>C</td>
<td>Brush down pressure</td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 3</td>
</tr>
<tr>
<td>D</td>
<td>Number of degreasing slotted vanes</td>
<td>200 PCS</td>
<td>250 PCS</td>
<td>300 PCS</td>
</tr>
<tr>
<td>E</td>
<td>High pressure water wash flow</td>
<td>80 L/min</td>
<td>90 L/min</td>
<td>100 L/min</td>
</tr>
<tr>
<td>F</td>
<td>Drying air knife CDA pressure</td>
<td>0.65 kg/cm²</td>
<td>0.85 kg/cm²</td>
<td>1.05 kg/cm²</td>
</tr>
<tr>
<td>G</td>
<td>Target film thickness</td>
<td>8.5 µm</td>
<td>9.0 µm</td>
<td>9.3 µm</td>
</tr>
<tr>
<td>H</td>
<td>SYP time</td>
<td>2700 ms</td>
<td>2800 ms</td>
<td>3000 ms</td>
</tr>
</tbody>
</table>
The value $\bar{y}$ of $P_1$ to $P_7$ number of defects is calculated by the earlier reported methods:\textsuperscript{12-14}:

$$\bar{y} = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7}{7}$$

The standard deviation $S_n$ of experimental conditions 1 to 18 is determined by:

$$S_n = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (P_i - \bar{y})^2}$$

Finally, the S/N (signal-to-noise ratio) is determined, as the purpose is fewer defects after photoresist coating, the S/N ratio equation of small-the-best characteristic is applied.

$$S/N = -10 \log \left( \frac{\sum_{i=1}^{n} y_i^2}{n} \right) = -10 \log (\bar{y}^2 + S_n^2)$$

**Results and Discussion**

The response of various control factors to the S/N ratio is calculated, with results recorded in Table 2, and the responses of various levels of factors to the S/N ratio are shown in Fig. 2. The importance of factors for S/N ratio is determined according to general standards. Afterward, the response of various parameter factors to quality characteristics is calculated, the results are recorded in Table 3, the responses of various levels of factors to quality characteristics are shown in Fig. 3, and the importance of factors for quality characteristics are determined according to general standards\textsuperscript{15-17}.

The eight control factors are divided into three types, according to importance for S/N ratio and quality characteristics, as shown in Table 3. Type 1 is the factors with influence on S/N, including B, C, F, and G, which factors reduce process variations. Type 2 is the factors with influence on quality characteristics, Factor H is of this type. This type of factors can be used to adjust the average value of quality.

**Table 2—Response of various levels of factor to S/N ratio**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>-16.19</td>
<td>-10.43</td>
<td>-19.78</td>
<td>-16.09</td>
<td>-16.24</td>
<td>-17.1</td>
<td>-17.18</td>
<td>-15.68</td>
</tr>
</tbody>
</table>

**Table 3—Classification of control factors and the eight control factors**

<table>
<thead>
<tr>
<th>Factor Type</th>
<th>Q1</th>
<th>Q2</th>
<th>Control factor</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>Yes</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For reducing variation</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>Yes</td>
<td>H</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For adjusting quality characteristic to target</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>No</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For reducing cost</td>
</tr>
</tbody>
</table>

Q1: Influences S/N? Q2: Influences quality characteristic?
characteristic to the target value without changing the variation of quality characteristic. This type of control factors is also known as adjustment factors. Type 3 is factors with no influence on S/N or quality characteristic, including factors A, D, and E. The design value of this type of factors will not influence function or quality, and can be used to reduce production costs.

The optimum process conditions are selected according to the classification of control factors, and the results are recorded in Table 4. The first type of factors give priority to the yield. The parameters include the electrical conductivity of degreasing fluid and target film thickness. However, roller brush down pressure will result in fragments. Although Type-3 has optimal yield, zero fragments remains the optimal selection. Therefore, Type-2 down pressure and drying air knife CDA pressure are selected, according to the results of S/N ratio and quality characteristic, where 1.05 kg/cm² is optimal. The second type of factors directly consider costs. A lower IR heating temperature can reduce the electric charge. The larger the number of degreasing fluid changing slotted vanes, the lower the consumption of water and abluent. The minimum flow rate of a high pressure micro jet is 80 L/min, which reduces the consumption of water.

When the optimum process conditions are imported into actual production, it is confirmed that photoresist coating film thickness and uniformity are apparently improved, with the average film thickness controlled at 15000±2000 Å, and uniformity is within 3% (as shown in Fig. 4), thus, the rejection rate of products resulted from photoresist defects is reduced. It is proved that the Taguchi method tested optimum process conditions can avoid abnormal film thickness or poor cleanness of substrate surface, thus, product defect rework or rejection is improved.

Table 4—Optimum process conditions

<table>
<thead>
<tr>
<th>Factor type</th>
<th>Control factor</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B</td>
<td>8.5 ms/cm</td>
<td>9.5 ms/cm</td>
<td>10.5 ms/cm</td>
<td>8.5 ms/cm</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 3</td>
<td>Type 2</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.65 kg/cm²</td>
<td>0.85 kg/cm²</td>
<td>1.05 kg/cm²</td>
<td>1.05 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>8.5 µm</td>
<td>9.0 µm</td>
<td>9.3 µm</td>
<td>9.3 µm</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>2700 ms</td>
<td>2800 ms</td>
<td>3000 ms</td>
<td>2700 ms</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>100–120°C</td>
<td>200–220°C</td>
<td>200–220°C</td>
<td>100–120°C</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>200 PCS</td>
<td>250 PCS</td>
<td>300 PCS</td>
<td>300 PCS</td>
</tr>
<tr>
<td>3</td>
<td>E</td>
<td>80 L/min</td>
<td>90 L/min</td>
<td>100 L/min</td>
<td>80 L/min</td>
</tr>
</tbody>
</table>

Fig. 4—Improvement of average film thickness and uniformity after optimum process conditions are imported

Conclusions

Competition in the touch control display screen industry is aggressive, and the only way to maintain enterprise competitive power is to continually upgrade quality, while reducing costs. In addition, it is necessary to continuously invest in large sized production lines in order to diversify products and increase added value. Enterprises must assume more efficient methods to shorten the time interval of bulk production.

(i) This study used the Taguchi method to determine optimal process parameters, paying equal attention to yield, productive capacity, and cost. The following conclusions can be drawn:

(ii) The process parameters and production yield of photoresist coating are improved, and the product obsolescence long-term level resulted from photoresist defect is controlled below 0.2%

(iii) The probability of defective products, and their probability of requiring reworking or repair by production line personnel, are reduced
The time interval from the establishment of a new production line to the stabilization of the process is shortened.

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References