

Ultra-high Precision Inkjet Printing Technology for Display

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Abstract

Inkjet technology has been used in display manufacturing since the color filter was manufactured on 2004. Also the inkjet-printed 40 inch OLED display prototype was demonstrated on 2004. Inkjet technology has penetrated various applications of display manufacturing such as PI alignment layer coating, liquid crystal coating, micro lens for back light, black bezel and more since 2004. However, it was mainly used for the overall coating or low printing accuracy applications up to now. The conventional printing accuracy of the inkjet technology was mentioned around ± 10 to $15 \mu\text{m}$ depending upon the printing condition. Now the advanced inkjet technology, which is mainly MEMS head technology and head control method, has been applied for more accurate, uniform and reliable printing than before. So the printing accuracy of the new inkjet technology has achieved up to $2 \mu\text{m}$ micro lens gap for micro lens array without any specific micro lens position zone defining treatment. This kind of micro lens array can improve the light extraction from the OLED lighting and display panel. Based on this printing accuracy, it can be possible for RGB pixel printing to achieve over 500 ppi (pixel per inch) with the well prepared PDL (Pixel Defining Layer) pattern.

Author Keywords

Inkjet Technologies; Printing Accuracy; Thin Film Encapsulation; RGB Pixel Printing; Micro Lens Printing.

1. Introduction

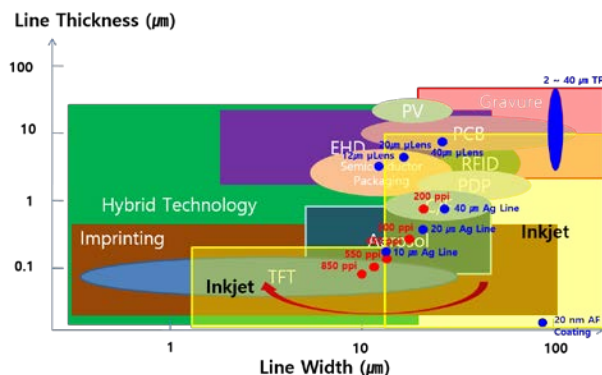


Figure 1. Target Line Width and Thickness of Inkjet Technology and its Printing Capability

Inkjet technology looks easy to be developed and applied into the display applications, but in reality it is very difficult to apply properly into the real device due to its intricately inter-related factors explained like below. Inkjet technology is consisted of the various factors such as ink, substrate, device and its design, device manufacturing process, inkjet head, inkjet printer, inkjet printing process, pre-process for substrate treatment, drying and curing. Also each factor is consisted of more than 10 sub-factors. For example, ink itself is consisted of the intricately inter-related sub

factors such as viscosity, surface tension, flow at channel, particle size, dispersion, wetting at the nozzle plate, pH, solid loading, colloidal stability, drying characteristics, types of carrier, polarity of the carrier and so on. So fundamentally the inkjet technology is governed by over 100 sub-factors. These sub-factors makes difficult the inkjet technology to be applied into the display.

The inkjet technology has been used a lot into the various applications of the display manufacturing ever since the early 2000s. However, it is mainly used at the selected coating applications due to its technical limitation, especially the low printing accuracy of inkjet technology. The printing accuracy of the conventional inkjet technology is mentioned around ± 10 to $15 \mu\text{m}$ depending upon the printing condition. Since there are many source of printing errors due to the droplet straightness and velocity variation of each nozzle, printing strategy, printing resolution, mechanical error of the XY motion stage and the alignment error. So it is necessary to minimize or remove these errors mentioned above for achieving ultra-high accuracy inkjet printing. The overall printing accuracy is not just related into one or two factors of the inkjet technology, but it is more related into the overall factors of the inkjet technology to be improved together.

The printing range of the inkjet technology as well as other technologies are shown at Figure 1. Inkjet technology is good to print at the range over $20 \mu\text{m}$ width line, however its limit is expanded below $20 \mu\text{m}$ by the smaller droplet size and advanced process know how. The LTPS TFEs in which $4 \mu\text{m}$ width source, drain and gate electrodes were inkjet printed by Seiko Epson together with zone defining surface treatment in 2006. The achievable thickness of the inkjet technology is varied a lot depending upon the ink types. The solvent based ink can achieve less than few micro meter thick, so anti finger print coating can be achieved thin up to 20 nm . On the contrary 100 % solid UV curing type ink can achieve 40 to $50 \mu\text{m}$ thick layer easily. It is possible for optical clear adhesive ink to achieve up to $100 \mu\text{m}$ thick layer with multi pass printing.

Now the maximum pixel printing resolution for 3 strip design of color filter has achieved up to 350 ppi, but it means just $24.2 \mu\text{m}$ printing resolution with 1 pl droplet. Also it means that 2 strip design of OLED can be printed up to 525 ppi. Since the droplet size can be reduced up to 0.6 pl with the current head technology, it is possible to achieve 550 ppi with 3 strip design and 825 ppi with 2 strip design. Of course, it should have the well-prepared PDL pattern to achieve the maximum resolution. The inkjet technology with less than $5 \mu\text{m}$ droplet size was shown at the couple of head manufacturers, even though it is not easy to commercialize it. However, it is believed that the droplet size can be reduced more up to 0.35 pl with new MEMS head design. The line width of the solvent based Ag ink can be printed up to $20 \mu\text{m}$ with 1 pl droplet size. But it can be printed up to $10 \mu\text{m}$ with the proper zone defining treatment technology and 1 pl droplet size.

Of course, it is also very important for high resolution pixel printing to achieve the highly accurate droplet position, especially for the large glass size. So the maximum pixel printing resolution is related into the glass size and its printer size due to the lower

accuracy of the large XY stage. But it is not necessary to achieve over 350 ppi printing for Gen. 8.5 or 10.5 glass size. Since it is targeted for larger panel size such as 55 or 65 inch display for TV, even though they need 10K resolution display.

Inkjet technology has a lot of advantages such as digital control, non-contact printing, droplet volume control, high printing accuracy, high productivity, environmental friendly and low cost. The most important advantages for display is the digital control, non-contact printing and droplet volume control. Due to these characteristics, inkjet technology is easily penetrating the display manufacturing applications with lower cost than the current technology. The applications will expanded more and faster than before with ultra-high precision printing capability. Also there are a couple of disadvantages of inkjet technology such as difficult ink development, limit ink viscosity range, and the surface treatment for droplet spreading control.

2. History of Inkjet Technology on Display Manufacturing

The history of inkjet technology for Display is shown in Figure 2. It was started at Japan due to the inkjet companies such as Seiko Epson and Cannon together with the cooperation of the display panel manufacturers. The first inkjet technology for display was introduced by Seiko Epson on 2004. Seiko Epson showed 40 inch 1280 x 768 pixel OLED display by manufactured by four 20 inch panel. Also CDT and Samsung showed small Polymer OLED displays on 2004 and 2005, respectively. However, the first mass production of PM OLED display by inkjet technology was conducted by Phillips on 2004. Philips applied this PM OLED display for the shaver. Sharp used the inkjet technology for mass producing the color filter on 2006. Korea display manufacturers are trying to develop the inkjet-printed color filter from 2006, but they were not successful for developing it for a couple of years. Except color filter and OLED, inkjet technologies are applied various areas such as PDP bus electrodes, LCD spacer, PI coating for LC alignment, and a-Si TFT during 2004 and 2007. Inkjet technologies are started to apply actively for the mass production of LCD in PI coating, liquid crystal coating and micro lens from 2008. Mass production of inkjet-printed TFE (Thin Film Encapsulation) was conducted by Philips for OLED lighting of Brite FL 300 on 2012. The development of inkjet-printed OLED was continued at Sumitomo, Panasonic and Sony, and LG Display followed to develop the inkjet-printed OLED display actively by using Gen. 8.5 glass size hybrid inkjet printing line from 2015. JOLED has started to produce 21.6 inch 4K OLED display for medical monitor and others on 2017. Also Nanosys and DIC has developed QD (Quantum Dots) color filter by inkjet technology on 2017, either. All display manufacturers are developing inkjet printing technology for OLED and QD display actively. It is expected to mass produce inkjet-printed OLED display pretty soon.

3. Accuracy of Inkjet Printing Technology

UniJet has developed the ultra-high precision inkjet printing technology. Figure 3 shows the square pattern inkjet-printed micro lens with the gap 3.24 μm ($\sigma = 0.32 \mu\text{m}$) and the pitch 36 μm ($\sigma = 0.38 \mu\text{m}$). And Figure 4 shows the hexagonal pattern inkjet-

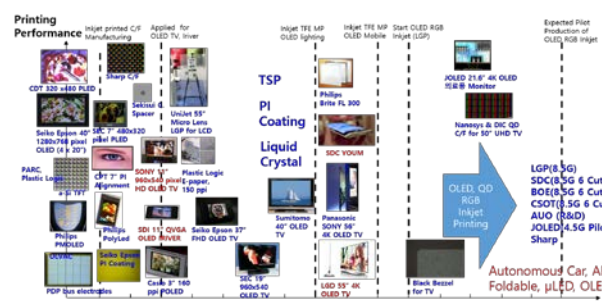


Figure 2. History of Inkjet Technology for Display

printed micro lens with the gap 2.28 μm ($\sigma = 0.086 \mu\text{m}$) and the pitch 28.8 μm ($\sigma = 0.21 \mu\text{m}$). They are showed the 2 μm gap and the tolerance of the gap has achieved within 1 μm at 3 σ condition. It means that the printing accuracy of this micro lens is less than 2.3 μm . Of course, there is a lot of inkjet factors optimized to achieve this result. But the accuracy of the inkjet printer itself is not the main factor of this printing accuracy result, even though the printing was conducted at 300 x 300 mm printing size. Since the accuracy of the smaller droplet can be improved due to the lower jetting height if the droplet size is reduced, the inkjet-printing accuracy can be improved more with the smaller droplet size. The surface condition should be uniform enough to get the accurate printing result without any pre-pattern. If there is existed good PDL pattern like OLED RGB printing, then it would be possible to achieve this level of accuracy more easily. Also one of the most important thing is the ink itself to perform the excellent jetting quality matched with the jetting head. Due to this accuracy of inkjet-printed marks, it is capable to use the alignment marks inkjet-printed on the substrate directly.

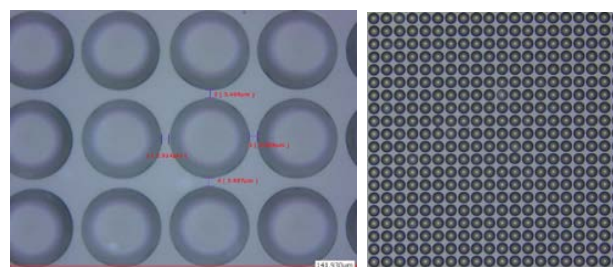


Figure 3. 3.3 μm gap square pattern inkjet-printed micro lens with the pitch 36 μm

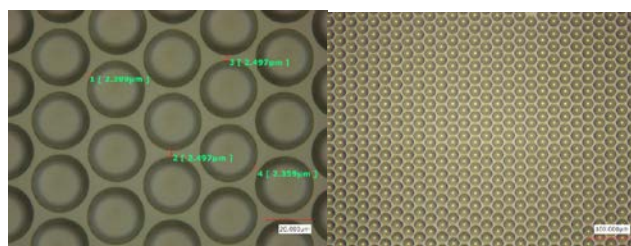


Figure 4. 2.3 μm gap hexagonal pattern inkjet-printed micro lens with the pitch 29 μm

4. Droplet uniformity of inkjet technology over the time

Long term droplet reliability and uniformity was always the big issue to be discussed for mass production of the inkjet technology. But the reliability and uniformity is more related into the environment and process condition than the head itself. The inkjet head for display application is made of piezoelectric actuator, so its performance is unable to be declined over time, even though the life time of the new sputtered piezoelectric actuator in the inkjet head is 5 times longer than before so it is reached over 680 billion actuations. Since the inkjet technology can be adjusted by digital method without any masks, it is possible to maintain the droplet more reliable and uniform than any other technology by adjusting the waveform related by the overall usage of the inkjet head. But the real life time of the inkjet head is still limited due to the high operating frequency than before.

The figure 5 shows the uniformity of the droplets over time. This uniformity test was conducted at the extreme condition which the temperature is changed over 10°C during the night of the full one day. However, the environment of the printer was controlled during the test. The variation of the droplet size was maintained below $\pm 0.1 \mu\text{m}$ for 24 hours. And the tolerance was within 0.09% like table 1. The droplet size during this test was measured by PDPA (Phase Doppler Particle Analysis) which has the volume measurement accuracy of $0.1 \mu\text{m}$ with $0.002 \mu\text{m}$ resolution.

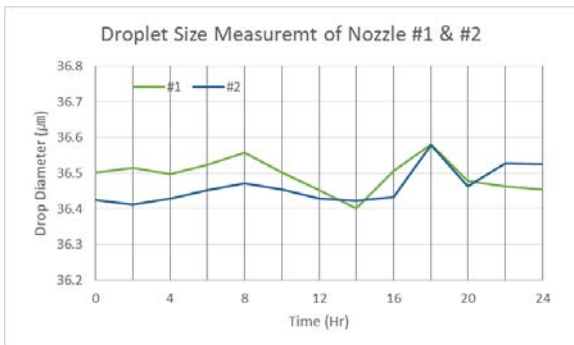


Figure 5. Inkjet droplet uniformity for 24 hours

Table 1 The uniformity result for 24 hour test

Nozzle #1 Avg.	36.495 μm
Nozzle #2 Avg.	36.493 μm
Difference between Nozzles	0.032 μm
Total Average	36.479 μm
Tolerance	0.09%

5. Control of edge shape of TFE

TFE of OLED display is one of area to apply inkjet technology actively, especially for mobile phone. TFE is consist of inorganic layer, organic layer and inorganic layer continuously for preventing humidity and oxygen from damaging OLED EML material. Inorganic layers are deposited SiNx or (and) SiOx less than $1 \mu\text{m}$ by PECVD, but PECVD is inevitable to generate the

particles natively. So one of the main purpose to deposit the organic layer is to cover the all particles generated by PECVD which can be the path of humidity or oxygen. The organic layer is usually deposited 100% solid UV ink from $4 \mu\text{m}$ to $10 \mu\text{m}$ thick by inkjet technology. Also the organic layer can release the stress of inorganic layer generated by PECVD deposition as well as achieve the planarization to deposit the next inorganic layer.

The target WVTR(Water Vapor Transmission Rate) of TFE is $10^{-6} \text{ g/m}^2/\text{day}$, which means one drop of water over six soccer fields per day. The inheriting performance of WVTR comes from the intrinsic WVTR, which is the layer properties of inorganic layer. But the most important factor of WVTR is the extrinsic WVTR which was results by the pinholes due to the defects, particles, porosity, substrate roughness and external damage due to thermal stress. The inkjet-printed organic layer can act the important role to eliminate the black spot due to extrinsic WVTR. The multi layers TFE technology was developed well by Vitex, but it was not proper to apply for mass production due to the low productivity and too high cost. Now the simple 1.5 dyads TFE configuration (inorganic-organic-inorganic layers) was developed well and it is applied a lot into TFE of OLED display for mobile.

One of the big issue of the organic ink printing for TFE is to form the edge top near the edge like coffee ring. This edge top can be eliminated by ink formulation itself, inkjet process, printing strategy and accurate droplet printing, so it is possible to get the uniform thickness within 2% like shown at Figure 5. To eliminate edge top and achieve uniform thickness at the edge is very important issue since it is generating additional problem at the next process continuously and the interference between the touch screen panel and display due to the noise. Another advantage of high precision inkjet technology for TFE is the capability to print the various edge shapes like notch and curved corner which was shown Apple iPhone X. Inkjet technology can solve a lot of issues with its advantages such as digital, non-contact and ultra-high precision characteristics.

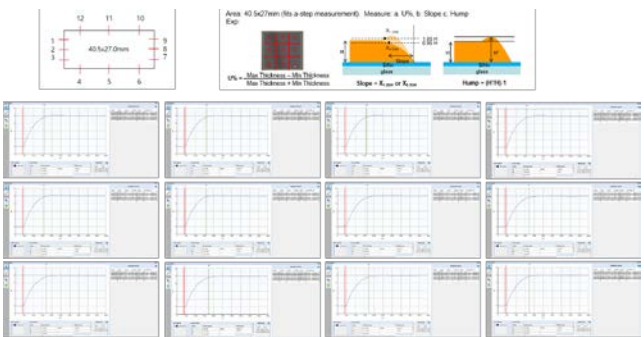


Figure 6. Result of Uniformity control at the edges by precise printing for TFE

6. Conclusions

Inkjet technology keeps advancing in all area since it was applied into display at the early 2000s. Based on this advancement, UniJet has shown that inkjet technology can achieve ultra-high precision printing up to $2.3 \mu\text{m}$ with $1 \mu\text{m}$ tolerance at 3σ range. And inkjet technology is reliable enough to conduct mass production for display manufacturing if the overall process is well developed and the ink itself is developed for the optimal target. It can be applied

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into the various area to need higher printing accuracy such as over 500 ppi OLED and QD color filter RGB printing and more, not just micro lens printing. However, there are a lot of factors to be developed and optimized together for achieving this result. TFE is one of the good area for inkjet technology to have been applied successfully. It is believed that the inkjet technology can be applied more and more area of display manufacturing.

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