Printing techniques

Painettavan elektroniikan jatkokurssi – 15.11.2011
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Benifits of printing for electronics and optics manufacturing

- High-speed fabrication
  - High volume products
  - Low cost manufacturing
- Flexible substrates, continuous web
  - Arbitrary size and shape
  - Integration in low-end products
- Established technology
  - Machinery etc. know-how exist
  - On the other hand…
- Additive methods
  - Waste reduction
  - Green issues

All together
  - Novel applications
  - Profit
Different printing techniques
Through put vs resolution

Gravure
Offset lithography
Rotary screen
Flexography
Flatbed screen
Thermal transfer
Inkjet
Soft lithography
Gravure printing

- Typically used to print high-quality and high-volume publications and packages [1,2].
- The advantages of gravure are:
  - the simple operation principle
  - simple-structured printing equipment
  - high production speed
  - high through-put
  - high resolution.
- Various solvents can be used since the printing cylinders are resistant to most inks.
- Disadvantages are:
  - the high costs of cylinders (> 1K€)
  - high quality demands for substrates
  - high requirements for suitable process parameters

Operation principle of gravure printing

Image elements are equally spaced but differ in area and volume (variable depth and variable area)
Operation principle of gravure printing

- The image-elements, i.e., cells are engraved into the surface of the printing cylinder whereas the non-image areas remain at the original level.
- The engraved printing cylinder rotates in an ink fountain as a result of which the entire printing cylinder is inked and flooded with ink.
- Excess ink is then wiped off with a doctor blade such that ink remains only in the cells.
- Ink is then transferred directly onto the substrate in a printing nip under pressure. The nip pressure is 1.5-5 MPa.
  - The ink transfer is often improved by creating an electric field across the nip. This field lifts ink out of the cells into contact with the substrate, thus improving the ink transfer. For example, the emptying degree of the cells increases from 40-60 % to 80-95 % with ESA (Electrostatic assist) system.
- The ink layer is dried by evaporating the solvent with hot air. [1]

Gravure cylinders

The printing cylinder engraving:
- electromechanically with a diamond stylus:
  - produces trapezoid-shaped as the stylus penetrates into the copper coating of the printing cylinder
  - geometry of the cell depends on the stylus angle
  - the penetration depth of the stylus
- laser-engraving:
  - produces round cells.
  - shape of the cell depends on the energy of the beam. [1,3]
- Etching:
  - Solid areas are also reproduced by engraving individual cells separated by cell walls
  - The ink has to spread to some extent to produce solid tones.
  - After engraving, the cylinder is chromed to increase its durability and improve the filling and emptying of the cells. [4,5]

Gravure cylinders

- Laser-engraving improves the filling and emptying of the cells due to its round shape.
- Laser-engraved cells are finer and produced faster than electromechanically engraved ones.
- Laser-engraving requires the printing cylinder to be coated with zinc instead of copper.
- The cells have been engraved in a form of a matrix of smaller dots (Extreme engraving). This allows a free adjustment of screen resolution, cell shape and depth, and cell wall thickness and reduces the raggedness of the printed lines. [3,6,7]
- The main factors affecting the print quality and ink transfer are:
  - The ink viscosity, ink type, printing speed, cell geometry, screen ruling (mesh=lines/cm), blade geometry, wiping parameters, nip pressure, ESA level, cylinder properties, and substrate roughness, pore structure as well as compressibility. [1]
- Gravure inks have very low viscosity (5-25 mPa•s) since they have to be able to flow in and out of the engraved cells at high speeds.
  => extremely thin ink layers are printed. The thickness of the ink layer is typically 0.8-2 µm but when UV-curing inks are used the thickness can be up to 8 µm. [1]


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Printing roll design

Example: effect of roll design in the printing quality

Gravure roll design

- 65 l/cm, 40 µm deep engravings
- 120 l/cm, 15 µm deep engravings
Gravure printed examples

PFBT printed on PEDOT:PSS layer from 2.5 wt-% p-xylene solution

Solvent with low boiling point

P3HT

Mixture of solvents with high and low boiling points

40-nm thick modified PEDOT:PSS print on ITO-PET
Flexography printing

- used mainly in packaging printing applications
- The main advantages are:
  - the wide variety of suitable substrates
  - simple operation principle and press construction
  - rather accurately adjustable applied amount of ink
- Disadvantages include:
  - the lower print quality
  - poorer register accuracy
  - lower printing speed
  - compared to other mechanical printing methods.
- the plate material limits the amount of suitable inks. [8,9]

Operation principle of flexography printing
Operation principle of flexography printing

- The image elements of the printing plate are raised above the non-image elements, forming a relief pattern of the printed image.
- Printing ink is applied onto the image elements via an anilox roller that has small cells engraved evenly onto its surface.
- The surface of the anilox roller is first flooded with ink from an ink chamber after which excess ink is removed with a doctor blade.
- As a result, ink remains only in the cells.
- Ink is then transferred onto the raised image elements of the plate and further onto the substrate.
- The nip pressure is 0.1-0.5 MPa.
- The plate is made of soft and flexible material which improves the contact formation at the ink transfer points.
- The ink layer is then dried with hot air. [1]
Anilox rolls

- Anilox rollers are typically coated with ceramic material or chrome and the cells are engraved onto its surface either electromechanically or with a laser-beam.
- Today, ceramic rollers are more common due to their smaller cell size.
- The ink release efficiency is typically 40 %. [10,11]


Flexographic printing plates

- Flexographic printing plates are typically made of photopolymer.
- These plates are first back-exposed to UV radiation to determine the relief depth.
- After this, the plate surface is exposed to UV radiation through a film negative.
- The exposed image areas polymerize and become insoluble. The unexposed material is then removed in a washing stage.
- CTP (computer-to-plate) plates are imaged directly from digital page data. The plates have a black coating onto which the page negative is formed by ablating it with a laser.
- Otherwise, the plate making steps are similar to the conventional plates. CTP plates have improved register accuracy. Thermal imaging improves the print quality further. [12-16]

Flexography

- The factors affecting the ink transfer and print quality are:
  - the cell geometry of the anilox roller, anilox roller type, ink viscosity, plate material, plate imaging, printing speed, nip pressure, and substrate properties. [1,15,16]
- Flexographic printing inks have low viscosity of 10-200 mPa·s contributing to the ink flow and improving the ink transfer. The ink layer thickness is 0.8-1 µm but with UV inks the thickness can be 2.5 µm. Recent developments in the laser engraving have increased the ink layer thickness to 6-8 µm. [1]
Offset printing

- is the most common printing method in newspaper and commercial printing in particular when high print quality is required.
- Offset printing plates are quickly and easily produced
  - the plates have a long lifetime since the plate is not in direct contact with the substrate.
- due to the high viscosity of inks drying can be done after the last printing unit.
- However, the ink-water balance needs to be accurately adjusted and the use of dampening water limits the range of suitable materials to be printed.
- Waterless offset removes the difficulties caused by the dampening water. In this case, silicone replaces water. [1]
Operation principle of offset printing
Operation principle of offset printing

- Offset printing is an indirect printing method where ink is transferred from the printing plate onto the substrate via an intermediate blanket cylinder.
- The image and non-image areas of the plate are on the same level but they have different surface energies: the image areas are ink-receptive and non-image areas ink-repellent but water-accepting.
- Dampening unit applies first a thin film of dampening water onto the non-image areas after which inking unit applies a thin layer of ink onto the image areas.
- The surface chemistry difference and the dampening water layer prevent ink from spreading onto the non-image areas. The dampening water also cools down the printing unit.
- The ink layer is then transferred onto the blanket cylinder and further onto the substrate.
- After the last printing unit, the ink layer is dried via absorption, polymerization, oxidation, or evaporation. [1]
Offset plates

- Offset printing plates are typically made of aluminium that is coated with a photopolymer layer.
- The photopolymer layer cross-links as it is exposed to UV radiation. The unexposed material can be then washed off with solvents.
- After development, the plate is protected and strengthened by gumming and baking.
- CTP plates are today popular since they eliminate the need of page films. However, these plates are more expensive but due to their sensitivity the exposure time and energy are greatly reduced.
- Nowadays, also thermal, chemistry-free, and process-less CTP plates are gaining popularity. These plates improve the print quality, eliminate several plate making steps, or offer energy and cost savings. [1,17,18]

Offset printing

- The print quality of offset printing depends on:
  - the ink properties, dampening water properties, substrate properties, printing conditions, ink-water balance, design of the inking and dampening units, as well as the plate and blanket properties.
- The quality of the offset printing is difficult and complicated to control. The most important quality factor is the ink-water balance that controls the amount of waste and ink transfer. [1,19]
- Offset printing inks have high viscosity (40-100 Pa·s). This high viscosity prevents excessive ink penetration into the substrate.
- The thickness of the ink film is typically 0.5-1.5 µm. Dampening water consists mainly of water (95-98 %) and additives such as isopropanol (IPA). IPA decreases the surface tension of water to increase the spreading rate of dampening water onto the non-image areas. [1]

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Screen printing (flat bed and rotary)

- Screen printing can be utilized at numerous applications such as printing textiles, advertisements, ceramics, curved substrates, and electronics.
- In addition, the range of suitable inks is large.
- On the other hand, the printing speed is low and often the print quality is also poor. [1,20]

Operation principle of screen printing (flat bed)
Operation principle of screen printing (flat bed)

- Screen printing is a push-through process where ink is pushed through a fine fabric (screen) made of plastic or metal threads.
- The non-image areas of the screen are covered with a stencil.
- The screen is flooded with ink which is pushed through the image areas of the screen onto the substrate by means of a squeegee.
- In order to tension the screen fabric, it is attached to a screen frame.
- The ink layer is then dried via evaporation, oxidation, or polymerization. [1,20]
Operation principle of screen printing (flat bed)

- The thread count and the mesh thickness determine the open screen area.
- This area should be large enough to pass though the pigments and fine enough to provide safe anchoring of the screen onto the smallest parts of the stencil.
- The stencil that is typically made of photopolymer is placed on the opposite side of the screen than the squeegee to avoid its wear.
- The thickness of the ink layer depends on the thickness of the stencil that ranges from 12 to 100 μm. [1,20]
Operation principle of screen printing (flat bed)

- The print quality is determined by the screen material, the fineness and thickness of the screen, as well as the degree of the open area of the screen.
- The screen fineness is typically 90-120 fibers/cm.
- In order to produce high print quality, the screen fineness should be approximately 3-4 times greater than the screen resolution (lines/cm).
- In addition, the ink, substrate, and squeegee properties and the print conditions affect the print quality. [1,20]
Operation principle of screen printing (rotary)
Operation principle of screen printing (rotary)

- Rotary screen printing enables higher printing speeds and increases the print quality.
- The screen has a cylinder shape and the ink is also placed inside this cylinder.
- The stationary squeegee located inside the cylinder pushes ink through the screen apertures onto the substrate as the cylinder rotates.
- The ink choice depends on the application as well as on the substrate.
- The ink viscosity must match to the desired ink layer thickness and the fineness of the screen.
- Typically, the ink film is 8-30 µm thick. [1]
Comparison

Typical dimensions for good printing results with major printing technologies

<table>
<thead>
<tr>
<th>Printing method</th>
<th>Viscosity [Pas]</th>
<th>Layer thickness [µm]</th>
<th>Feature size [µm]</th>
<th>Registration [µm]</th>
<th>Throughput [m²/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravure printing</td>
<td>0.05-0.2 [22]</td>
<td>0.8-8 [22]</td>
<td>75 [29]</td>
<td>&gt;10 [29]</td>
<td>60 [29], 3-30 [30]</td>
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<td>0.01-0.03 [VTT]</td>
<td>&lt;0.1 [24-26, VTT]</td>
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<td>0.8-2.5 [22]</td>
<td>80 [29]</td>
<td>&lt;200 [29]</td>
<td>10 [29], 3-30 [30]</td>
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<td>0.04-0.1 [27]</td>
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<tr>
<td>Offset printing</td>
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<td>10-50 [29]</td>
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<tr>
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<td>2-3 [29]</td>
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References

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References

VTT creates business from technology