Screen Printing

- Basic process allows deposition of a layer of controlled thickness onto underlying substrate
  - Basic process can be traced back more than 3000 years to Chinese silk screen printing of fabrics
  - Still used in this role today
- Main process components are
  - Screen
  - Printing head
  - Tooling system to hold substrate
- Used across electronics and technical ceramics industry for deposition of controlled thickness layers in the range of 5-40µm
- Wide range of applications from dielectrics, resistors, conductors, solder pads,
- Substrate can be either rigid or flexible
The printing cycle

**Model Cycle**

A - Ink placed between screen and print pattern
B - Downward pressure applied and squeegee moves forward
C - Ink forced through mesh, screen “snaps” up behind blade (off contact printing)
D - Print deposited, pressure releases, squeegee continues over ink ready for return stroke (“hop over” not required in dual trailing edge systems)

- Alternative are single print strokes often in conjunction with flood blades
- Often used where printing direction can affect accuracy of deposit (asymmetrical patterns)
The Screen

• Made from woven filaments
  • Various materials can be used polyester, nylon
  • Various weaves can be used
  • Selection depends on substrate and print type

• However stainless steel often used in thick film ceramic applications
  • Stability, wear resistance,
  • Accuracy in pattern registration (less stretch)
  • More prone to puncture damage

• Mesh defined by filaments per inch, eg 200, 325
  • Mesh tensioned over frame
  • Often at 45° mesh angle for better line definition

• Pattern generated from UV photoresist emulsion
  • Emulsion can be various thicknesses
  • Can be used to meter print thickness
  • Needs to be matched to solvent type

• Important aspects for specifying screen
  • Mesh type, number, tension, angle, emulsion type, thickness, frame size

Selected Characteristics for Stainless Steel Meshes

<table>
<thead>
<tr>
<th>Mesh Count (per inch)</th>
<th>Filament Dia (micron)</th>
<th>Open Area (%)</th>
<th>Approx Aperture Size (micron)</th>
<th>Approx Wet Print thickness (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>50</td>
<td>46</td>
<td>106</td>
<td>57-117</td>
</tr>
<tr>
<td>165</td>
<td>50</td>
<td>41</td>
<td>104</td>
<td>50-116</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>36</td>
<td>77</td>
<td>45-115</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
<td>46</td>
<td>-</td>
<td>45-92</td>
</tr>
<tr>
<td>325</td>
<td>27.5</td>
<td>41</td>
<td>42</td>
<td>27-62</td>
</tr>
</tbody>
</table>
Printing Head

- Applies pressure and motion to the squeegee
- Moves ink and forces it through screen pattern
- Pressure and speed are important printing parameters
- Two main designs in use
  - Trailing edge
  - Square section (also known as diamond blade or section)
- Squeegee material mainly polyurethane polymer
  - Many grades available, classified by hardness
- Grade will depend on needs of contour following, edge retention and wear resistance
- Drive can be
  - Manual
  - Hydraulic
  - Electro-mechanical

- Trailing Edge inherently flexible
  - Generally conforms better good for uneven substrates, multilayer printing
  - But only single direction print without dual head
  - Deforms at high pressures
  - Limited use with high viscosity inks
- Diamond section far more rigid - dual direction on single head
  - Good for high viscosity – can aid control of layer thickness lower scalloping
  - Not good if substrate bowed or for multilayer
Ink Rheology During Printing

- A combination of forward motion and angle of attack generate pressure and shear within the ink
  - In a pseudoplastic ink this reduces the viscosity and forces it through the screen mesh
- Blade angle of attack depends on blade hardness and printing pressure
  - Higher angles promote ink rolling
  - Lower angles increase pumping effects
- Changes in substrate height can cause changes in angle
  - Leads to print thickness variation
  - Trailing edge deals with this better
- High viscosity inks and high velocities can cause trailing edge blade to “float” above ink leading to inconsistent prints
- Some level of thixotropy good for post print surface levelling and elimination of mesh marks
Effects of Thixotropy in Print Levelling

![Graph a](image1)

- ▲ Glycerol + 2 wt% PVP

![Graph c](image2)

- ▲ PG/water 100/0 + 5 wt% PVP
- ▲ PG/water 90/10 + 5 wt% PVP

Shear stress (Pa) vs. shear rate (s⁻¹)
The Printed Layer

- Ink generally meters to mesh height
  - Especially in large area prints
- Edge effects present in all prints
  - Greater effect on thickness in small area prints
  - Thicker emulsions will amplify this
  - "zero" emulsion minimises these effects
- Thickness can be built up using multiple prints
  - Print-dry-print (PDP) cycles
  - Although these also have limits
- Small adjustments in thickness can be made through ink viscosity, speed, pressure, print gap
Refining The printed layer

Set up and Process Variables

**Printer Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>For A Thinner Print</th>
</tr>
</thead>
<tbody>
<tr>
<td>squeegee pressure</td>
<td>high</td>
</tr>
<tr>
<td>squeegee speed</td>
<td>low</td>
</tr>
<tr>
<td>squeegee angle</td>
<td>high</td>
</tr>
<tr>
<td>squeegee hardness</td>
<td>high</td>
</tr>
<tr>
<td>screen gap</td>
<td>low</td>
</tr>
</tbody>
</table>

**Process**

- Mesh thickness: reduce
- Emulsion thickness: reduce
- Paste viscosity: reduce

Other factors which will affect print thickness are temperature, squeegee wear, screen tension and ink quality

**Other Factors**

<table>
<thead>
<tr>
<th>Factor</th>
<th>For A Thinner Print</th>
</tr>
</thead>
<tbody>
<tr>
<td>room temperature</td>
<td>high</td>
</tr>
<tr>
<td>(hence viscosity)</td>
<td></td>
</tr>
<tr>
<td>squeegee wear</td>
<td>low</td>
</tr>
<tr>
<td>screen tension</td>
<td>low</td>
</tr>
</tbody>
</table>
Effects of Ink Quality

• Agglomerates in an ink or on the surface of a tape will lead to stress raisers in printed layer, this will in turn lead to cracking on sintering or even drying.

• Agglomeration will also lead to rheological inconsistencies as agglomerates break down and reform in changing shear conditions.

• If you see you have agglomerates in your tapes or inks it is worth spending time refining your processing and eliminating them – look at your milling protocols and dispersant choices.

Flaws present on tape surface leading to electrolyte layer cracking

Tape with few flaws resulting in good quality electrolyte layer with few defects
Drying

• To allow for working time on screen low volatility solvents used to give ink its fluidity (eg terpineol)
• Similar processes to tape drying but lower volatilities and thinner layers reduce some of the issues
• Heavier solvents require increased temperatures for drying
  • Generally 80-120°C
• Lab based development use standard drying ovens
  • Sometimes a short room temperature drying period useful
  • Can avoid cracking
  • Allows residual higher volatiles to evaporate
• Industry will use tunnel oven with substrates on chain link belt
• This gives controlled heating and cooling ramps
Electronic Components

- 30μm lines/spaces (10-20μm in development) _circa 2010_
- Hybrid circuits often encapsulated in glass or resin
- Incorporated into larger devices via Surface Mount Technology
- Applications include RFID tags, Biosensors, Flexible displays, Flexible circuitry, PV Solar
Building up a multilayer device

COMPLIMENTARY PRINTING

- Early Multi layer technique
- Minimised step changes
- Involve extra printing cycles
- Good registration required
- Improvements in thinner layer depositions have reduced application on this technique

VIA FILLING

- Improvements in thin layer printing reduced step heights
- Here a complete layer of dielectric is printed over conductor
  - Over print contains vias for electrical connection
  - Via fill & top conductor can be printed in 1 or 2 passes
- More complex devices attainable
- Good registration still required
Thick Film Resistors

• Thick film resistors are blends of electrically conducting or semiconducting ceramics with glass
  • Common materials are RuO$_2$, Bi$_2$Ru$_2$O$_7$, Pb$_2$Ru$_2$O$_6$ also Ag-Pd-PdO mixtures
• Resistance specified in sheet resistance (ohms per square) (Ω/□)
• Resistivities of mΩ/□ to MΩ/□ can be created by blending conductive and resistive phases
• Glasses phases (also known as frits) generally lower firing 700-900°C
• Fine tuning of resistance values can be achieved post firing by trimming resistors
• Allows for dimensional variance during firing

Sheet Resistance

• For a given material & thickness all square sheets have the same R
  • Known as sheet resistance (Ω/□)
  • The value of any resistor can be calculated by multiplying $\rho$ by the number of squares
Stencil Printing

- Stencils cut from metal sheet rather than screen
- Good for thicker layers
- Often used for solder paste in surface mount technology
- Coarser solder particle too large for fine screens
- Use of Diamond section squeegee
- Metal blade can be used in place of squeegee
- “On contact” printing method common
Multiple Screen Printing in Solid Oxide Fuel Cells

- Series connected cells
  - Give low currents and high voltages
  - Cells build up by sequential printing
  - Individual firings used – cofiring would be better

- Structural support is cheap inactive material
  - Avoids cost of high purity active material for bulk quantities
  - All active materials in thin layers

Air outside
Fuel inside
Section through one wall of tube

- Interconnect
- Cathode
- Electrolyte
- Anode
- Porous tube wall
Combining Tape Casing and Screen Printing in SOFC

Use of screen printing for thinner electrochemical layers
Matching thickness against function
Cofiring for single thermal process

Integrated gas flow channels via Chevron Printing
Industrial Tape Casting & Screen Printing

Courtesy Versa Power, Calgary

These processes are flexible & scalable to high volume and low cost production.
Printing Line Automation

Automation essential for mass production
• Improve throughputs
• Reduce operator influence
• In line QC
• Improved registration and accuracy
• Some lines capable of 2-3M components in single shift
• Printing of multiple components before trimming

Ancillary systems required
• Substrate Dispensing
• Feed Through the Print Position
  • The Print Position
  • Feed to the Drying System
• Feed from the Drying System
  • Pick and place systems
• Reloading Magazines or Cassettes
  • Print Parameter Storage
    • Vision Systems