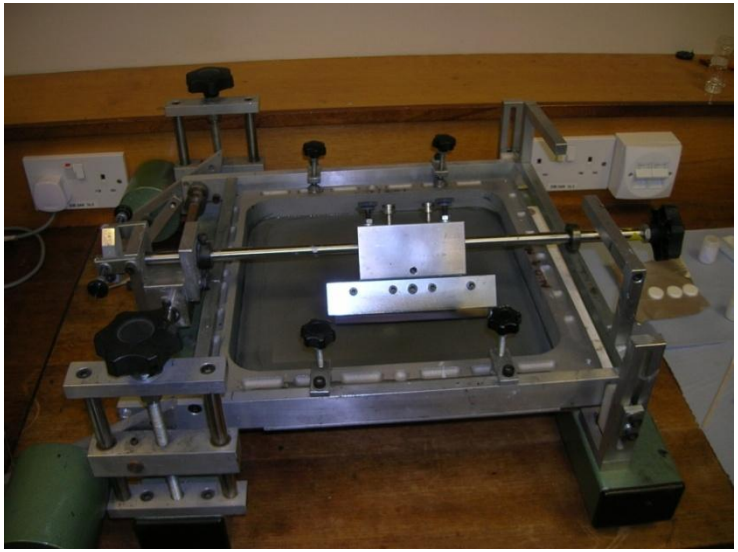
CH5716
Processing of Materials

Ceramic Thick Film Processing

Lecture MC7 – Screen Printing Processes

Screen Printing

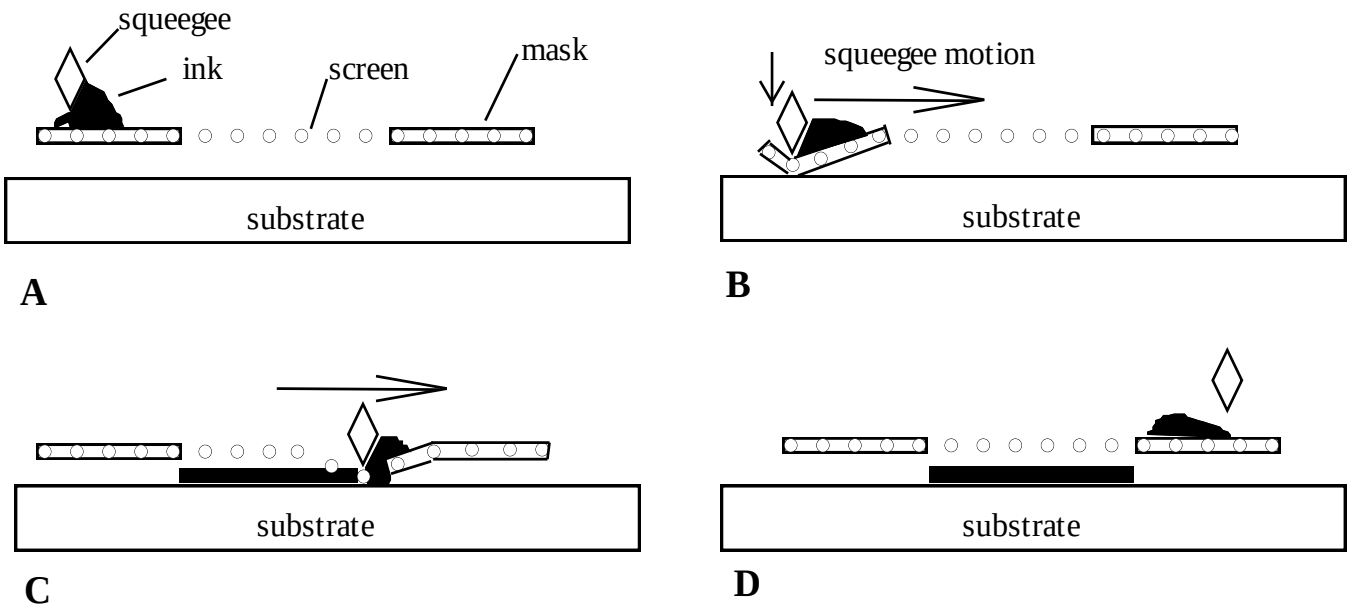


Simple hand operated printer

Semi automatic industrial development printer

- 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

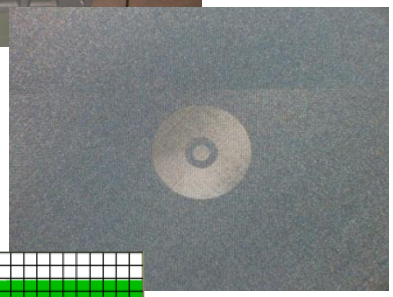
B - Downward pressure applied and squeegee moves forward

C - Ink forced through mesh, screen “snaps” up behind blade (off contact printing)

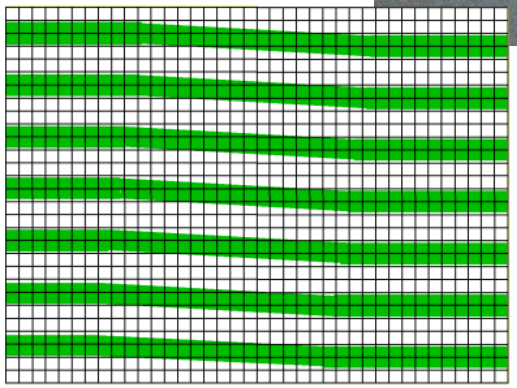
D- Print deposited, pressure releases, squeegee continues over ink ready for return stroke (“hop over” not required in dual trailing edge systems)

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

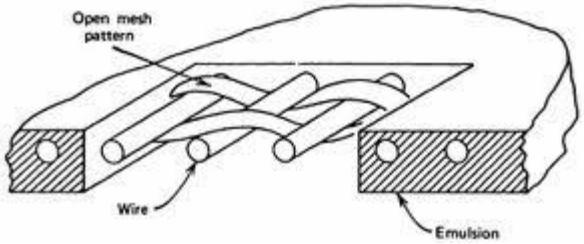
The Screen



- 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



Example of saw tooth effects
if tracks & mesh are parallel



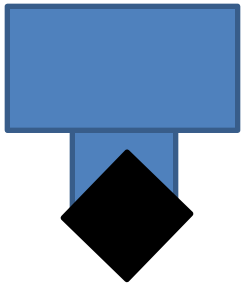
Selected Characteristics for Stainless Steel Meshes

Mesh Count (per inch)	Filament Dia (micron)	Open Area (%)	Approx Aperture Size (micron)	Approx Wet Print thickness (micron)
150	50	46	106	57-117
165	50	41	104	50-116
200	50	36	77	45-115
200	40	46	-	45-92
325	27.5	41	42	27-62

Printing Head

Trailing edge squeegee

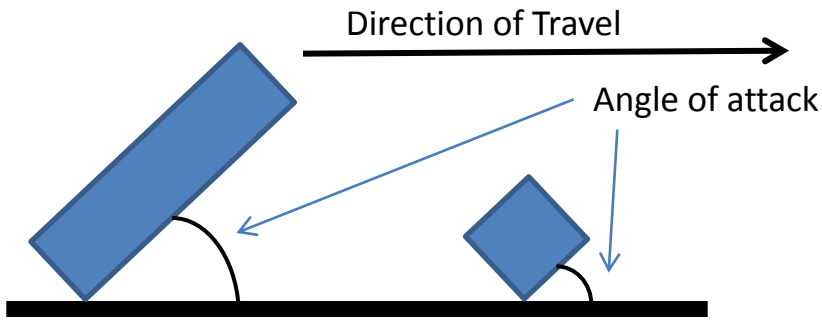
- Applies pressure and motion to the squeegee
- Moves ink and forces it through screen pattern
- Pressure and speed are important printing parameters
- Two main designs in use
  - Trailing edge
  - Square section (also known as diamond blade or section)
- Squeegee material mainly polyurethane polymer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

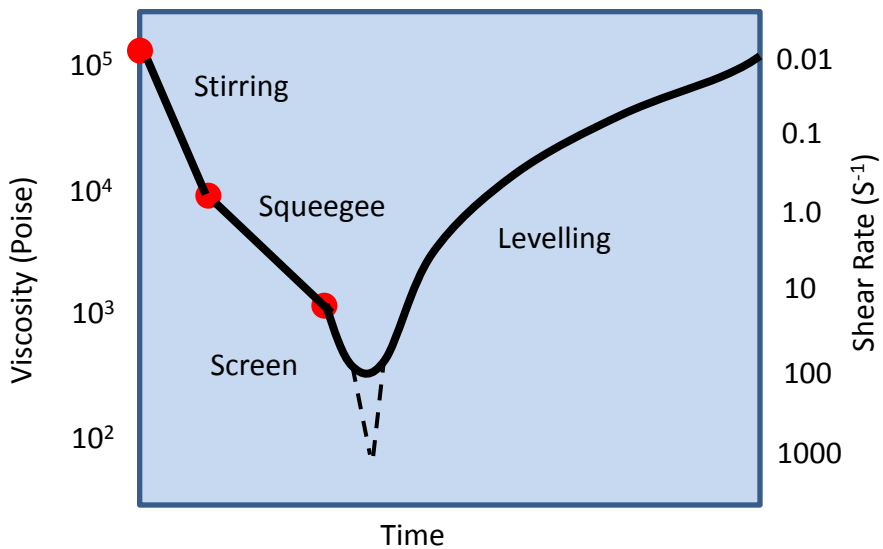


Square (Diamond) section squeegee

- 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

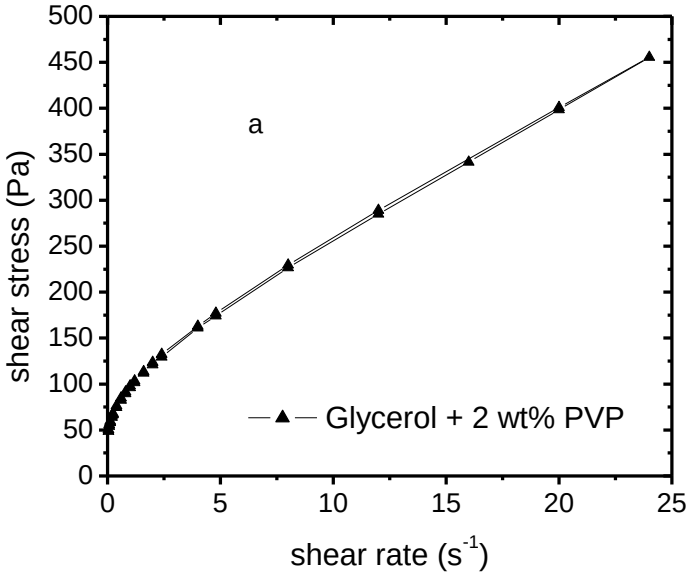


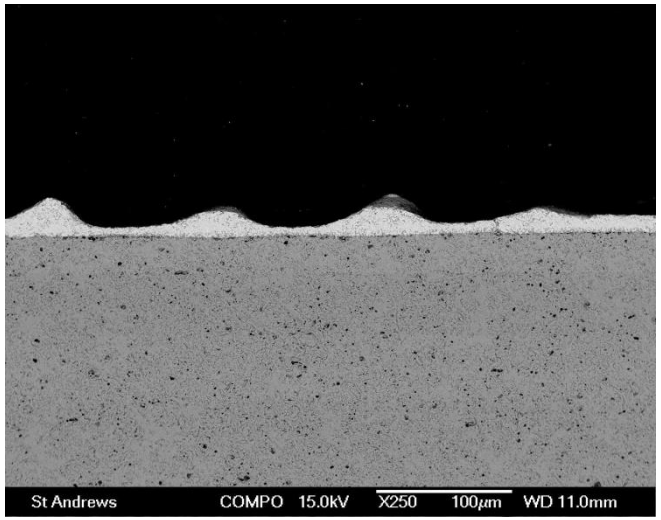


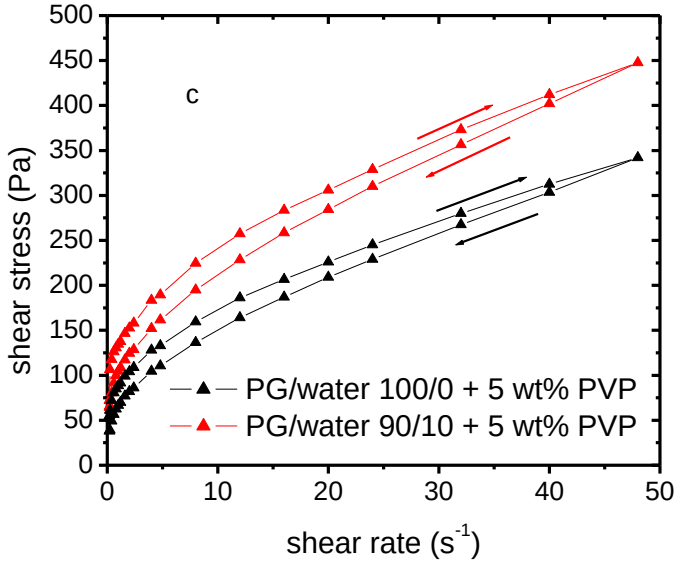
- A combination of forward motion and angle of attack generate pressure and shear within the ink
  - In a pseudoplastic ink this reduces the viscosity and forces it through the screen mesh
- Blade angle of attack depends on blade hardness and printing pressure
  - Higher angles promotes ink rolling
  - 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

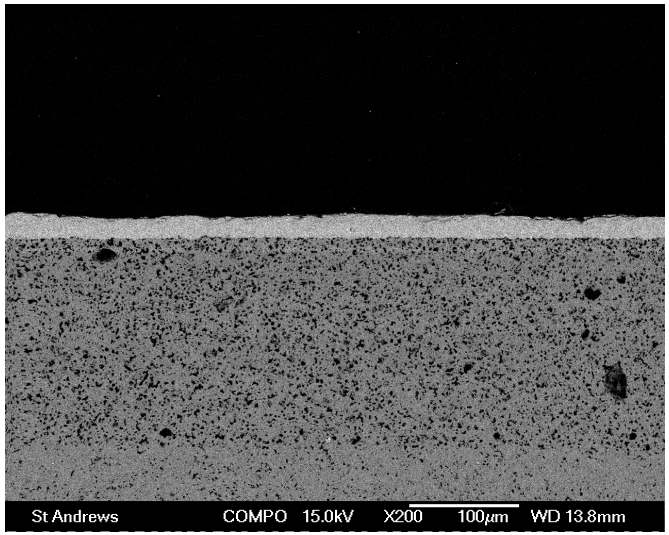
- Some level of thixotropy good for post print surface levelling and elimination of mesh marks

Effects of Thixotropy in Print Levelling

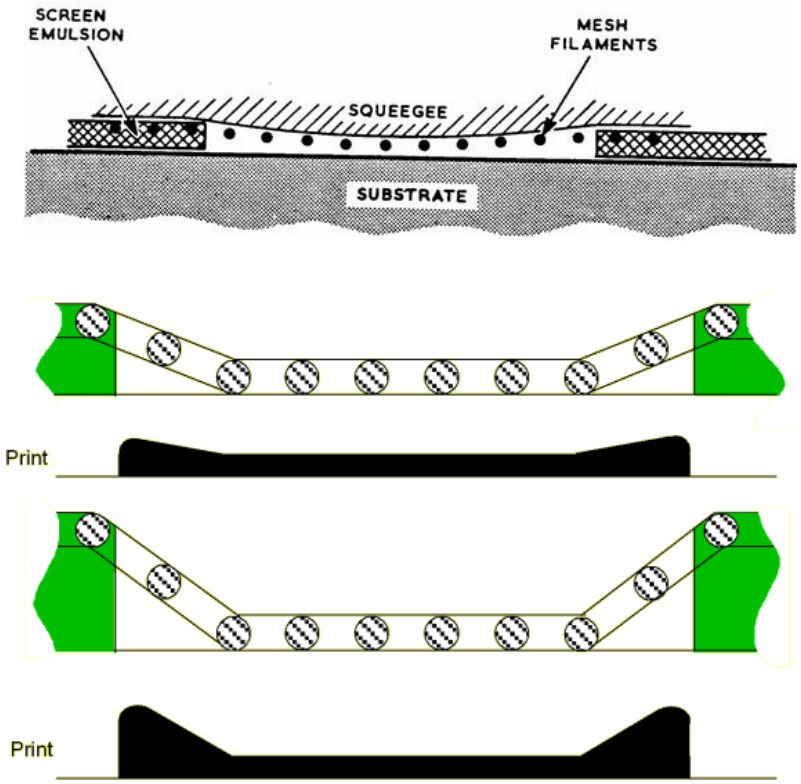




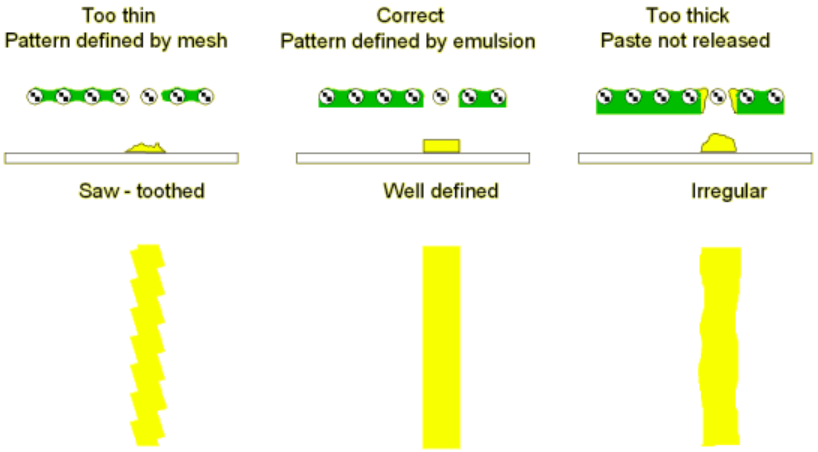




The Printed Layer



- 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	FOR A THINNER PRINT
squeegee pressure	high
squeegee speed	low
squeegee angle	high
squeegee hardness	high
screen gap	low

PROCESS	For Thinner Print
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	FOR A THINNER PRINT
room temperature (hence viscosity)	high
squeegee wear	low
screen tension	low

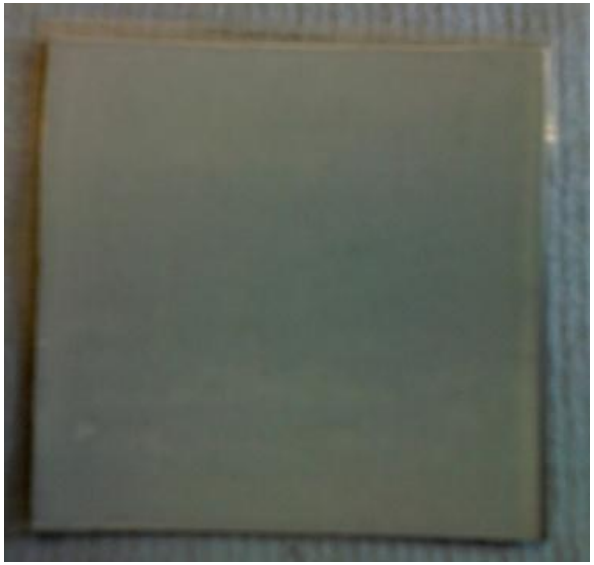
Effects of Ink Quality

•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

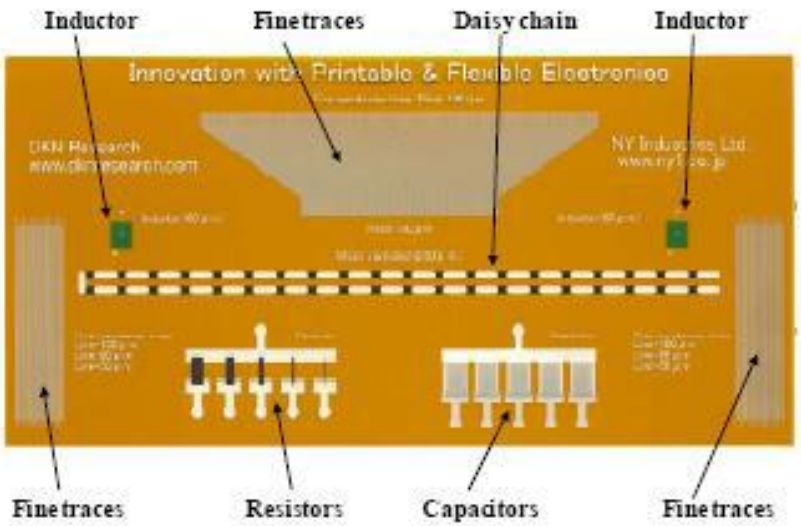


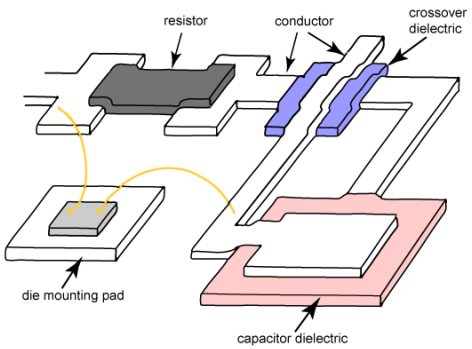
Tape with few flaws resulting in good quality electrolyte layer with few defects

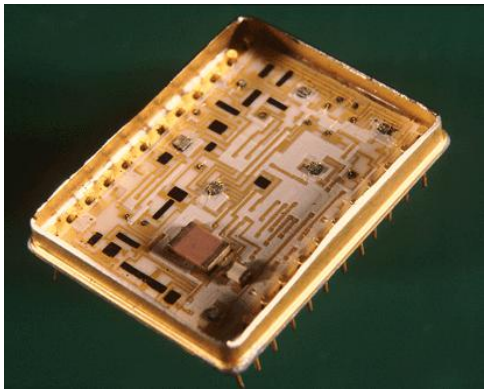
Drying

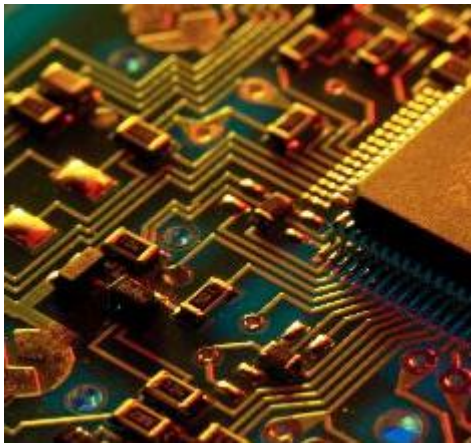
- To allow for working time on screen low volatility solvents used to give ink its fluidity (eg terpineol)
- Similar processes to tape drying but lower volatilities and thinner layers reduce some of the issues
- Heavier solvents require ncreased temperatures for drying
    - Generally 80-120°C
- Lab 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

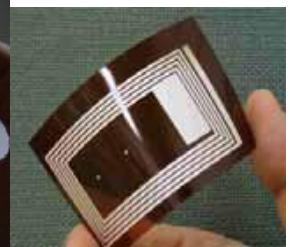


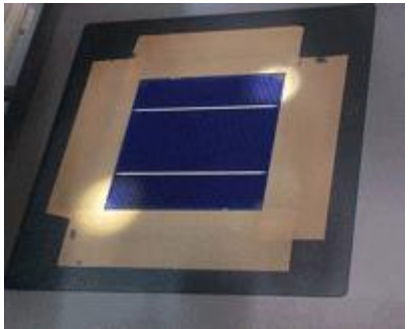






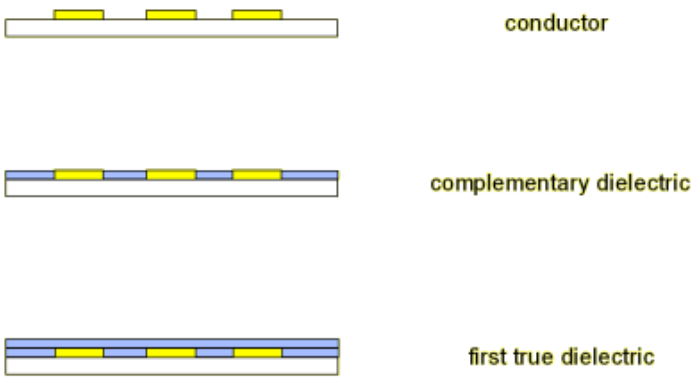
- 30µm lines/spaces (10-20µ m in development) *circa 2010*
- Hybrid circuits often encapsulated in glass or resin
- Incorporated into larger devices via Surface Mount Technology
- Applications include RFID tags, Biosensors, Flexible displays, Flexible circuitry, PV Solar





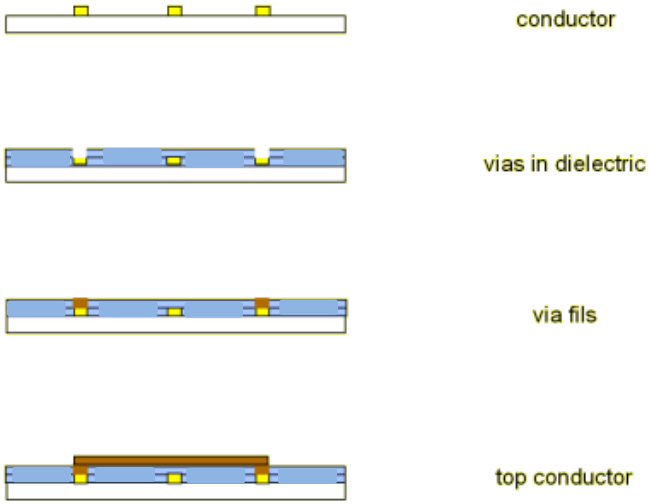
Building up a multilayer device

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

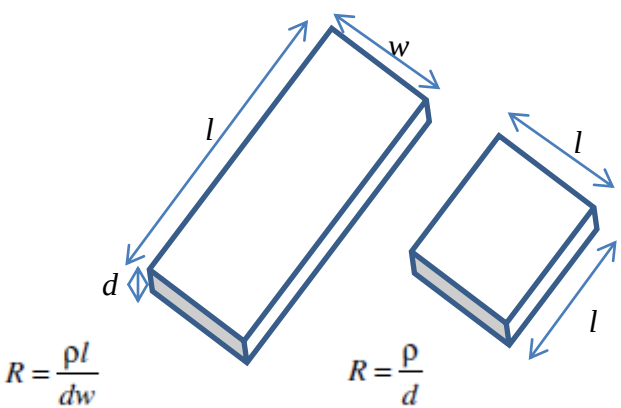


- Improvements in thin layer printing reduced step heights
- Here a complete layer of dielectric is printed over conductor
- Over print contains vias for electrical connection
- Via fill & top conductor can be printed in 1 or 2 passes
- More complex devices attainable
- Good registration still required

Thick Film Resistors

- Thick film resistors are blends of electrically conducting or semiconducting ceramics with glass
  - Common materials are RuO_2, $Bi_2Ru_2O_7$, $Pb_2Ru_2O_6$ 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 ρ by the number of squares

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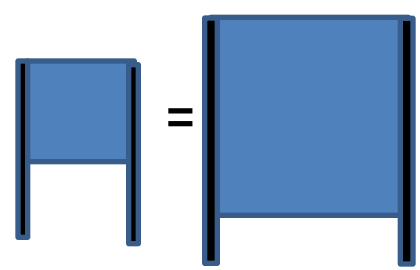
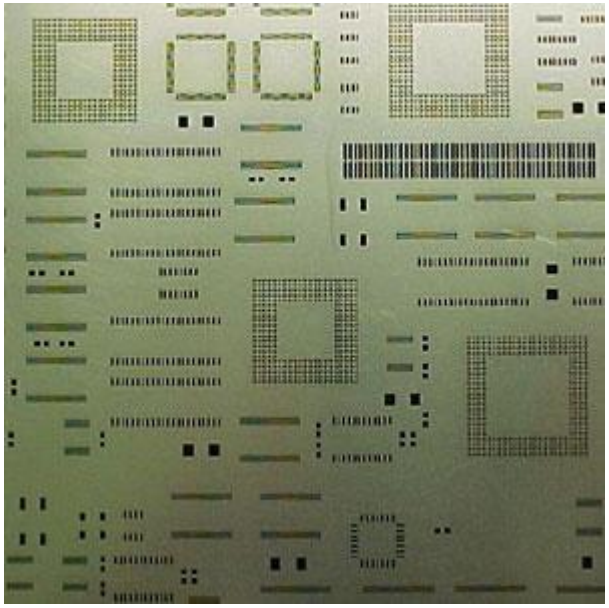
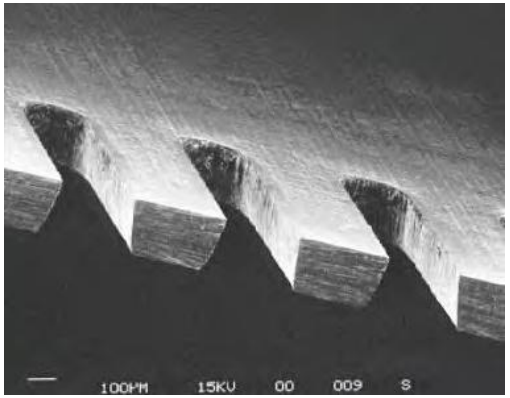
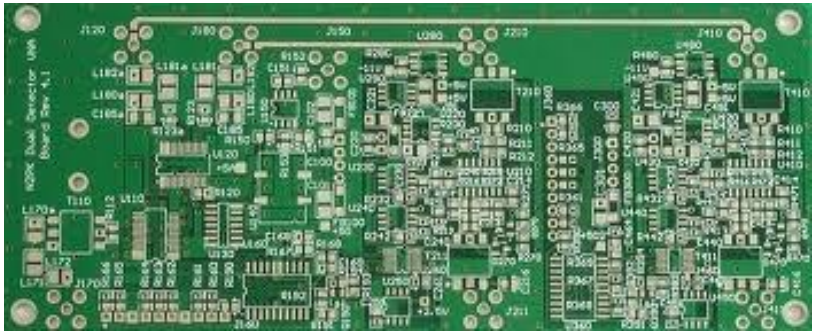


Stencil Printing

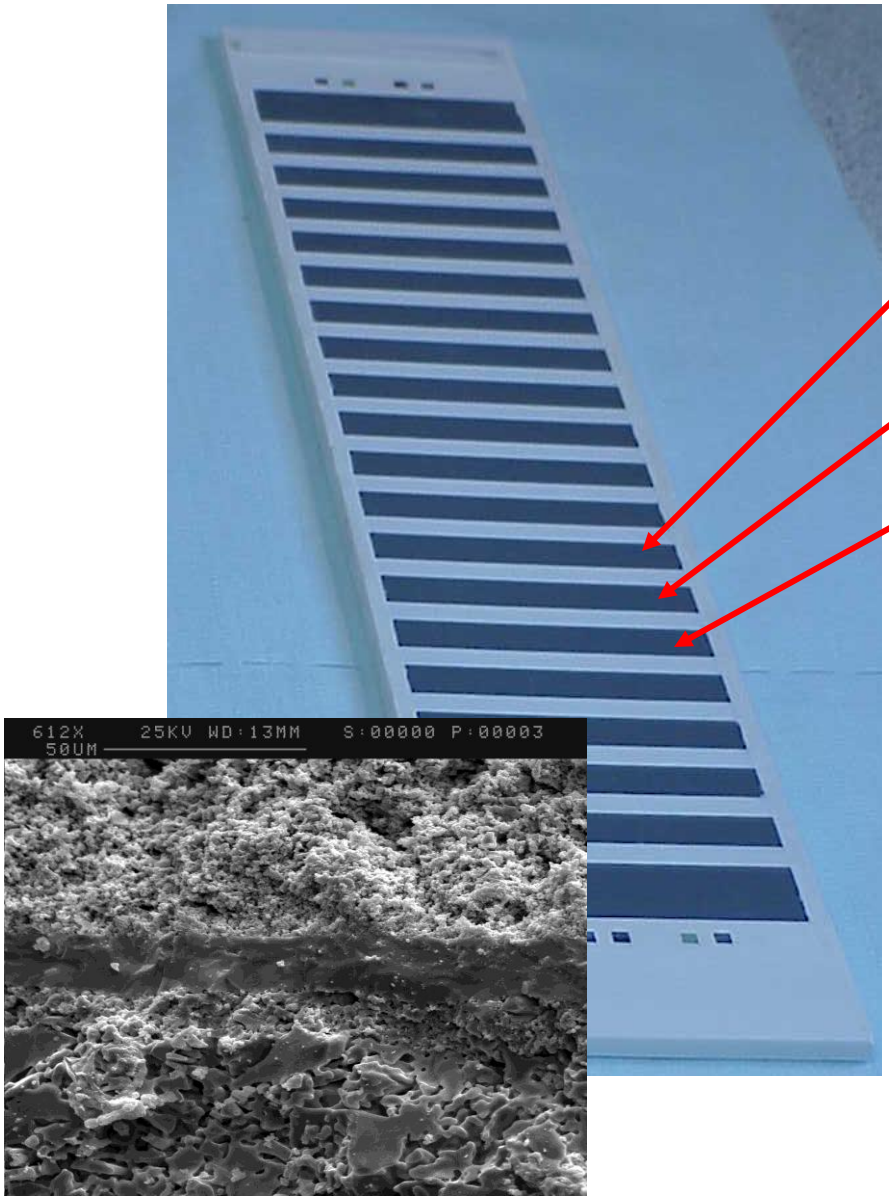


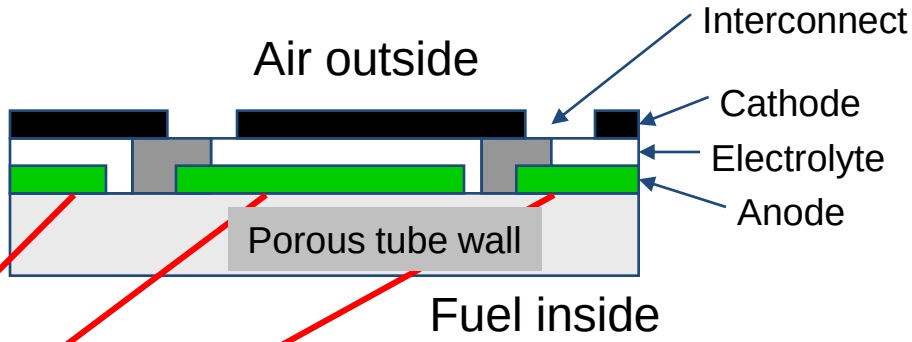
- Stencils cut from metal sheet rather than screen
- Good for thicker layers
- Often used for solder paste in surface mount technology
- Coarser solder particle too large for fine screens
- Use of Diamond section squeegge
- Metal blade can be used in place of squeegee
- “On contact” printing method common





Multiple Screen Printing in Solid Oxide Fuel Cells

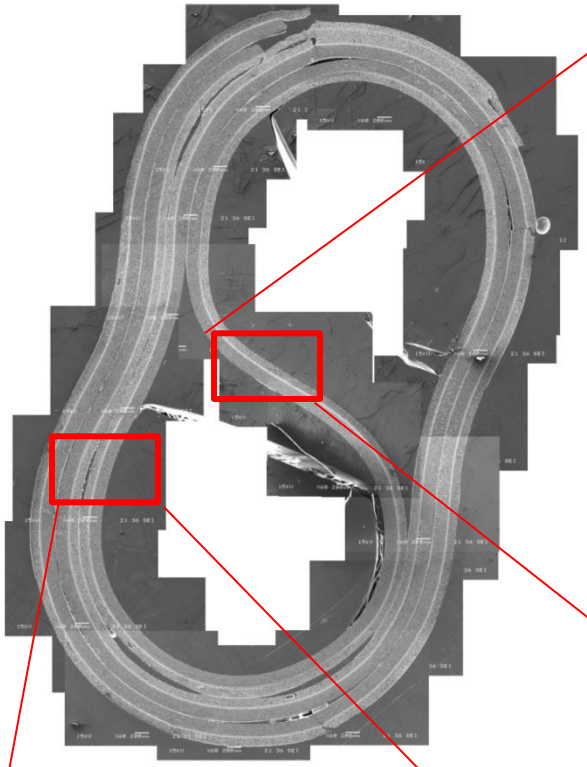


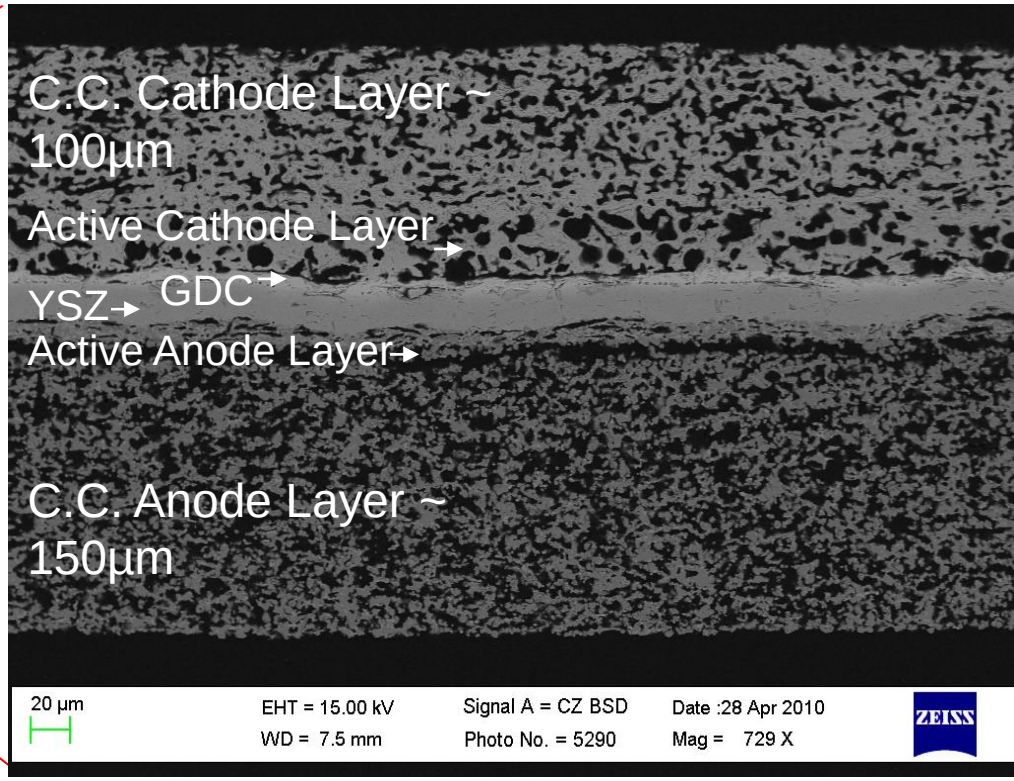


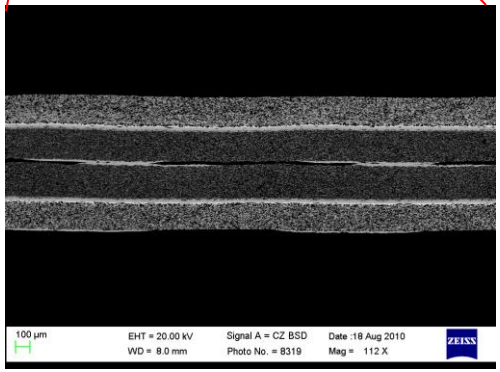
Section through one wall of tube

- 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

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

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