THE HURDLES AHEAD FOR INKJET
MEETING FUTURE APPLICATION REQUIREMENTS

Vince Cahill, VCE Solutions
Dene Taylor, PhD, SPF, Inc.
IMI Inkjet Conference, February 6, 2015

VCE Solutions, SPF-Inc & The Solutions Group

- Provides technical & marketing consulting & planning services for digital & analog printing, imaging & fabrication system manufacturers & users
- Conducts market research & analysis, monitors & evaluates technological developments, facilitates printing technology implementation & business planning
- Focuses on industrial, textile & graphic arts printing & deposition solutions, markets & public relations issues

Conference Caboose Advantages

- Others who have gone before have prepared the way
- Mark Hanley: Inkjet's unstoppable momentum
- Single-pass: promise and problems
- Offset inkjet: more promise
- Mike Willis revealed the inkjet innovations in the patent pipeline

Debbie Thorp
Inkjet Development is Complex

GLOBAL INKJET SYSTEMS
CONTROL | PERFORMANCE | INNOVATION

- Customer acceptable image quality
- Parameters:
  - Drop placement accuracy
  - Drop quality
  - Edge acuity
  - Optical density
  - Function

- Issues:
  - Inks & substrates
  - System configuration
  - Process
  - Software
  - Color management
  - Jetting errors
  - Image artefacts
  - Nozzle drop outs
  - Etc.....

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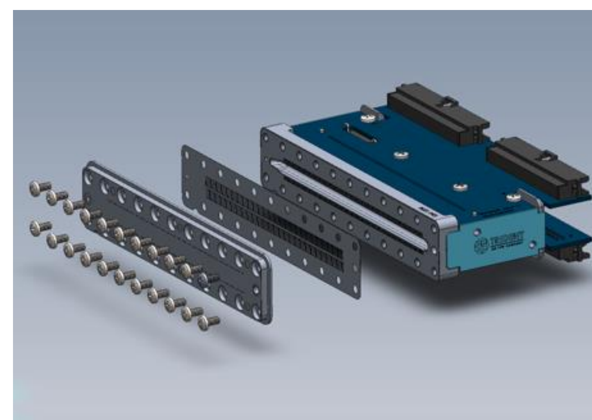
Alchemie Expanding Jetting

Jetronica

- Coating thickness to 50 microns
- Viscosity range 2 cP to 500 cP
- Sub-micron to over 20µm
- Aqueous, oil, solvent, UV

Trijetica

- Trident durable PIJ push mode
- User refurbishable
- 7 to 80 pL



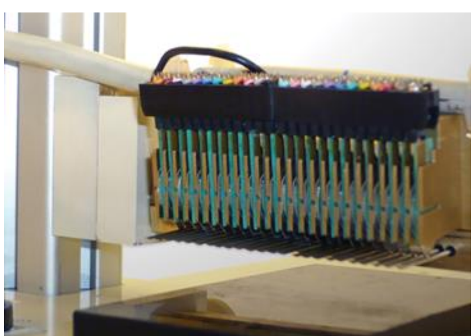


Photo source: Alchemie

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Breaking News

- Steinemann Technology AG dmax
- Digital system for UV spot varnishing
- Sheet size up to 108 x 78 cm
- Less treatment, with little varnish pinhole free, 600 dpi resolution

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Why Focus on the Hurdles Ahead

- While Inkjet Technology appears to have “unstoppable momentum”, for some applications, BUT …
- It has limitations and faces barriers for other areas
- What are the areas & barriers; will they be surmounted?
- Change is inevitable.
- Adapting to disruptive change is the way to survive & prosper
- Failure modes, hurdles, adversities & challenges are sources of opportunity
- Innovation begins with a problem to solve

Content

- Limitations that inkjet must overcome to satisfy customer expectations for digital print growth applications
- Comparison of current analog print & manufacturing methods vs. inkjet's current performance capabilities
- Possible strategies for overcoming inkjet's current limitations
- Alternative and novel digital deposition technologies that may disrupt inkjet for some applications

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Digital Print Growth Applications

- Printed electronics
- LED, PLED, OLED displays & lighting
- Photovoltaics
- Packaging
- Ceramics
- Masking for handling protection
- Resists for etching
- Selective coating
- Regenerative medicine
- Medical dosing
- 3D Additive Manufacturing
  - Injection molding replacement
  - Molten metal
- Commercial production
- Textiles & garments

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Expectations & Requirements

- Same or better performance from analog print or fabrication
- Enough for the purpose
- Cost effectiveness
- Specific to applications
- Consistency
- Equal to its task
- Accuracy & precision
- Longevity: to last as long as needed
- Outdoor durability
- Chemical resistance
- Abrasion resistance
- Rigidity to flexibility
- Tensile strength
- Sustainable
- Non-toxic & safe to use

Inkjet Advantages & Drivers

- Cost effective short runs
- Print width arrays = faster production speeds
- Variable print
- Photo-image quality
- Minimal prepress (& waste?)
- Precise material deposit
- Can print fragile, dimensional, all size substrates
- Enables inventory risk reduction & JIT delivery
- Faster prototyping, sampling, customization & to market
- Eliminates film, screen & plate storage
- Enables fast distribute & print virtually everywhere & web-to-print

Inkjet Limitations

- Jetting fluid constraints
  - Jetting viscosity <20cP
  - Materials tolerated
  - Solvent evaporation
  - Surface tension range
  - Interlayer adhesion
- Nozzle diameter limits jet-able particle size
  - Log jamming potential
- Finer particle grind = greater cost
- Multi-channel drop variability
- Air currents divert drops < 5pL from placement
- Frequency of drop generation decreases with the increase in drop volume and also with increase in firing fluid viscosity
- Process color
- Chemistry & curing
- Deposit thickness

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Definitions: Viscosity

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid.

@ 20^{o}C:

- air = 0.02 cP
- water = 1.0
- corn oil = 72
- glycerin = 1490
- ketchup = 50,000+

Measures:

- Poise (P), centipoise (cP)
- Pascal-second (Pa·s)
- 1 cP = 1 mPa·s

Here we define:

- Low viscosity @ 20^{o}C : 0 to 50 centipoise (cP)
- Medium viscosity: >50 cP to 1,000 cP
- High viscosity: >1,000cP

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Print Methods & Fluid Viscosity

- Most Inkjet: < 30 cP
- Screen print: 1,000 to 10,000 cP for most graphic applications; up to +50,000 cP for some plastisols, polymer thick films & adhesives.
- Offset lithography: 40,000 to 100,000 cP
- Flexography & Gravure: 50 to 500 cP
- Generally, the longer the polymer chain the greater the viscosity
- Rule of thumb: viscosity decreases by 2% for each degree Celsius rise for fluids

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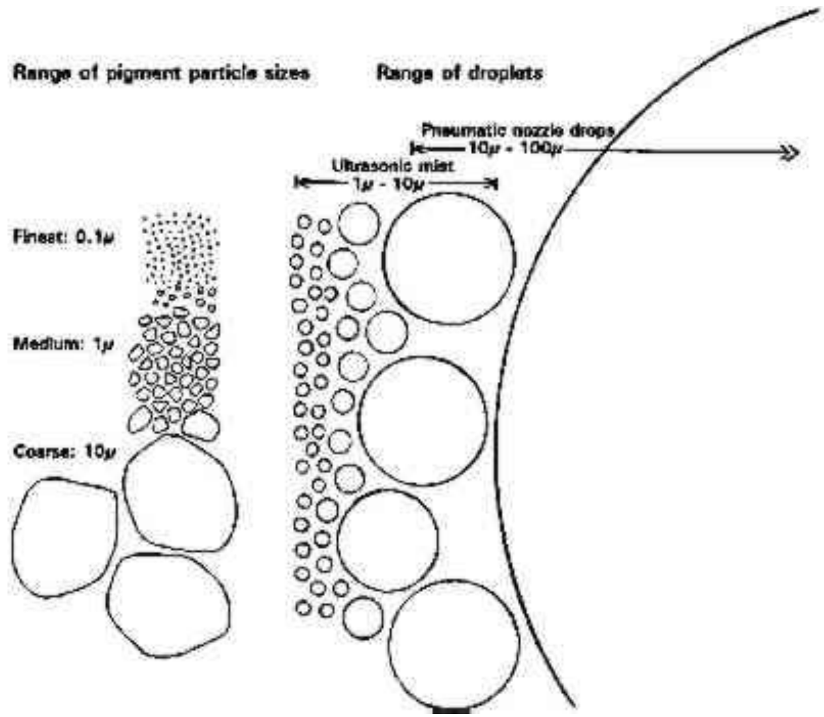
Definitions: Particle Size (Grind)

- Longest dimension of largest particle
- Rule: maximum particle size should be 1/50th the diameter of inkjet nozzle diameter or smaller to avoid particles log jamming
- Inkjet nozzle diameters are typically in the range of 10 to 50 micrometers (µm)
- Maximum particle size can then be 0.2 to 1µm
- The finer the grind, the greater the cost

- Inkjet 4-color pigment particle size: 0.1 to 0.3µm
- Inkjet single color: 0.2 to 1µm



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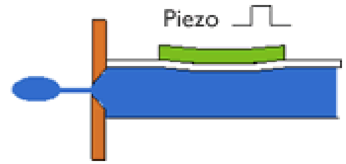
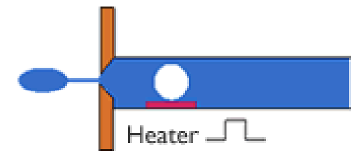
Other Hurdles



DOD - Piezoelectric



DOD - Thermal Inkjet

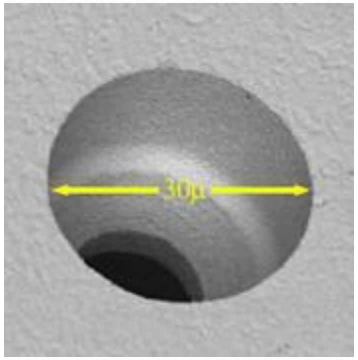
- Ink & substrate surface energy compatibility
- Controlling drop-substrate impact and dot spread
- Satellite drops & drop ligament dot distortion
- Lack of on contact pressure

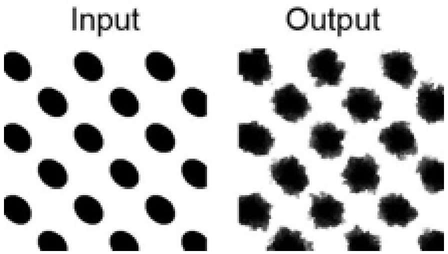
- CIJ: Electrolytic & $$ head
- TIJ DOD: 350-400^{o}C koga & limited head life
- PIJ DOD: $$ print head
- Environmental factors:
  - Lint & dust
  - Temperature
  - Humidity
  - Altitude/pressure

Image source: Xennia

Particles, Nozzle Diameters & Dot Gain

- Particles whose longest dimension is greater than 1/50th in of the diameter of the nozzle
  - Epson PrecisionCore: ~20µm nozzle diameter
  - Fujifilm Dimatix Galaxy PH 256/80: 52µm
  - EDMs orifice diameters in the 6µm to 250µm range
  - Microdrop: 30 to 100µm nozzle diameter
- Substrate impact on dot gain
- Banding
- Jet-outs





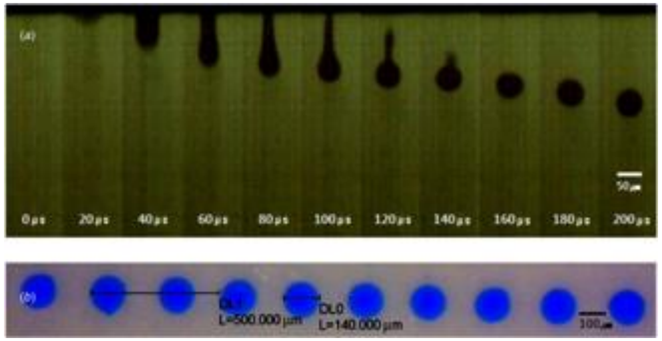


Image source: http://www.micromanufacturing.com & he-print-guide.blogspot.com

Contrasting

Inkjet

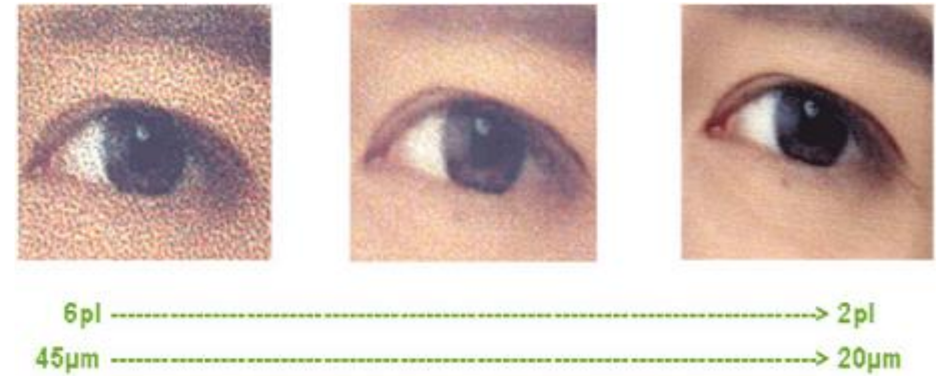
- Non-contact
- Variable image drop deposit (thin)
- Surface energy of ink & substrate most significant force
- Material surface energy – ink surface tension => 20mN/m
- Typical drop volume range from 1 to 80pL
- Scanning to full width

Analog (Screen)

- On contact lateral and downward force of print action typically sufficient to overcome or reduce the effect of surface energy
- Fixed image film deposit
- Thick deposit
- Full width
- Higher viscosity and larger particle deposition
- Lower material cost

Commercial Production (momentum)

- Competing with offset litho image quality & speed
- Speed: page wide arrays
- Variable data, fast change
- MEMS making heads
- Epson PrecisionCore, Fujifilm Samba & J-Press 720, Konica Minolta KM-1800i & K1, Canon Oce Kyocera KJ4+ Jet Stream, Screen Truepress Jet520, Ricoh InfoPrint 5000, Kodak Prosper, HP WebPress



Packaging (scratching the surface)

Formats:

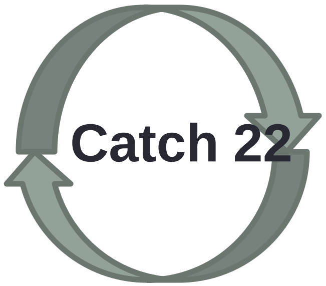
- Single pass roll for labels, flexible packaging and light cartons
- Single pass sheets for folding carton, carrier and corrugated
- Flat bed multi-pass for carrier and corrugated boards
- Fixed head rotating for containers and tubes

Hurdles:

- Labels – low
- Other areas - Prices
  - Brands find unit costs high

    “Large volumes will lower costs

    Low costs will grow volumes”
  - Solution? Sell now at prices anticipated in future?



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Inks for Packaging

	Appeal	Hurdles
Aqueous	• Not burdened with regulatory restrictions	• Unable to dry food grade inks at speed on films
Rad-cure (UV/EB)	• All substrates • Intense color, white & metallic	• Applications limited by migration concerns • EB cure not yet launched (soon)
Transfer (Landa)	• Promises substrate independence	• Find out soon

Packaging: Folding Carton

- Corrugated & heavy card
- Corrugated plastic
- UV & aqueous
- Large print head scanning arrays to Single-pass
- Successors to FastJet
- Scanning: Inca Digital, Durst, HP Scitex, EFI Vutek
- Single-pass: Sun Automation Group, Barberan

Rho 1000 Corrugated
(Image source: Durst)

Barberan Jet Master 840, 1050, 1260

Sun Automation's CorrStream 20
Image source: Sun Automation Group

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Packaging

- In-line, Roll-to-roll & Flatbed
- CIJ, PIJ & TIJ for marking & case coding mature & widely adopted
- Competition from toner based digital, i.e. HP Indigo
- UV cure migration issues for food packaging
- Analog methods, i.e. gravure, offset, flexo, very cost effective for long runs
- Inkjet useful for prototyping folding carton, short runs, selective coating
- Inkjet labels proving cost effective for short to medium print runs. Recirculation of white & metallic

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Digital Textile Printing (starting to move)

- DTG established but not cost competitive for long runs
- Inkjet’s non-contact process provides advantage for printing elastomeric fabrics
- Placement of production inkjet printers from MS, Reggiani, La Meccanica, Durst, Konica Minolta & others
- Single-pass roll-to-roll presses, e.g. MS LaRio, begin to offer production speeds to match screen
- Overcoming inertia of current analog printer placements with expensive new equipment
- Indirect sublimation

Konica Minolta Nassenger Pro 1000

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Inkjet Production Textile Printing

- Konica Minolta Nassenger Pro 1000: 1000m^2/hour at 540 x 360 dpi (Scanning)
- MS LaRio: 35 to 75 linear meters per minute (up to 320cm print width) 600 dpi

- LaMeccanica Qualijet Tiger 88: 320 linear m/hr at 600 dpi. 180, 240, 340 cm print widths, 600 dpi
- Reggiani ReNOIR
- Robustelli-Epson MONNA LISA
- Durst Kappa 320
- TenCate-Xennia

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Digital Textile Print Applications

- Apparel & accessories for women, men and children
- High value items
- Sportswear & swimwear
- Uniforms
- Home textiles: curtains, sheets, towels, table settings, furniture upholstery
- Carpets (Milliken & Zimmer since 1975)
- Textile packaging & bags
- POP/POS
- Automotive and transportation upholstery
- Flags & banners
- Architectural, transportation & industrial textiles
- T-shirts & specialties
- Gaming covers
- Trans-dermal dosing
- Smart garments & textiles

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Inkjet DTG Printing

- Anajet M-Power & Sprint
- Brother GT-3 series
- DTG Digital Viper 1 & 2, M2, M4 & M6
- Equipment Zone Veloci-Jet XL
- Aeoon KYO DTG

- Epson SureColor F2000
- Lawson Diamond-Jet
- Kornit Avalanche 1000, Breeze, Thunder, Hexa, Storm II, Paradigm II
- Summit DTG 520

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Ceramics

- Large particle settling issue
- Dimatix StarFire & Xaar 1002 (+ others) ink recirculation, agitation and larger drop
- Advantages of inkjet over screen winning adoption for tile printing

Durst Gamma Series

Durst InkShaker

EFI C4 Cretaprinter

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Transfer Textile Decoration +

- Sublimation IJ: BASF, Sawgrass, EFI, Mimaki, Roland, Mutoh etc.
- Sublimation Offset +
- Sublimation transfer papers: Forever, Epson, Cham Paper Group Transjet, Joto TexPrint
- Desktop inkjet transfer paper: Avery
- Laser print transfers: ATI
- Plotter-cut & IJ print heat transfers: Stahl's, Poli-tape, Specialty Materials, Chemica, R-Tape, Siser etc.

Mimaki CJV 30

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3D Printed Undergarment

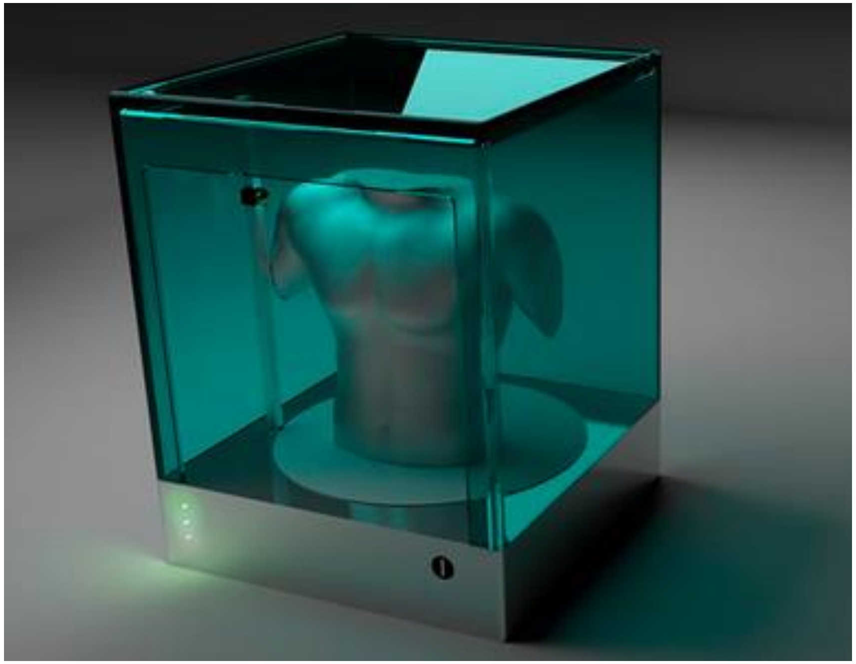
CosyFlex Process

- U.K.-based Tamicare
- Biodegradable & customizable fabric
- Comes in any desired shape, with no fabric waste
- Spray of latex, cotton or other fibers extruded to form layers of a breathable fabric
- For sportswear, bandages & undergarments.
- Machine can make a pair of briefs in under three seconds
- 10 million per year capacity

Photo source: http://textually.org

Electroloom 3D Clothing Printer

- Work in progress



- Printed designs from online CAD-file
- Goal to produce well-wearable clothes using cotton

Source images: Electroloom

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3D Printing Users / Applications

- Regenerative Medicine
- Pharma & Cosmetic
- Architects, Industrial Product & Packaging Designers
- Aerospace & Automotive
- Machinists & Makers
- Construction
- Advertising
- Stage & Screen Design
- Educational Institutions

- Bio-medical organs
- Architectural models
- Product prototypes
- Air & spacecraft & auto parts & models
- Machine props
- PV cells
- Buildings
- Stage props & set models
- Training

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Inkjet & 3D AM Methods

- Vat Photopolymerization: Stereolithography (SLA), (MSL), (FMSL) Film Transfer Imaging (FTI), Solid Ground Curing (SGC)
- Material Jetting: Polymer Jet Printing, Multi-jet Modeling
- Binder Jetting: Powder Bed 3D Inkjet (ExOne, 3D Systems, HP)
- Material Extrusion: Fused Deposition Modeling, Robocasting
- Powder Bed Fusion: Direct Metal Laser Sintering, Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Selective Heat Sintering (SHS), Electron Beam Melting (EBM)
- Sheet lamination: Laminated Object Manufacturing (LOM), Selective Deposition Lamination (SDL), Ultrasonic Consolidation (UC) (UAM) (VHP UAM)
- Directed energy deposition: Electron Beam Freeform Fabrication (EBF^3), Laser Engineered Net Shaping (LENS)
- Building Structure Print: D-Shape & Contour Crafting

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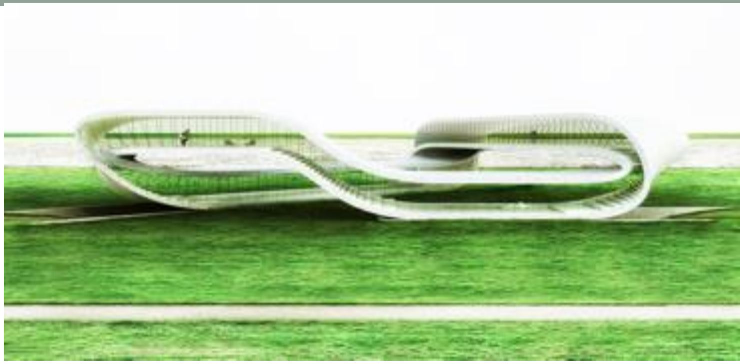
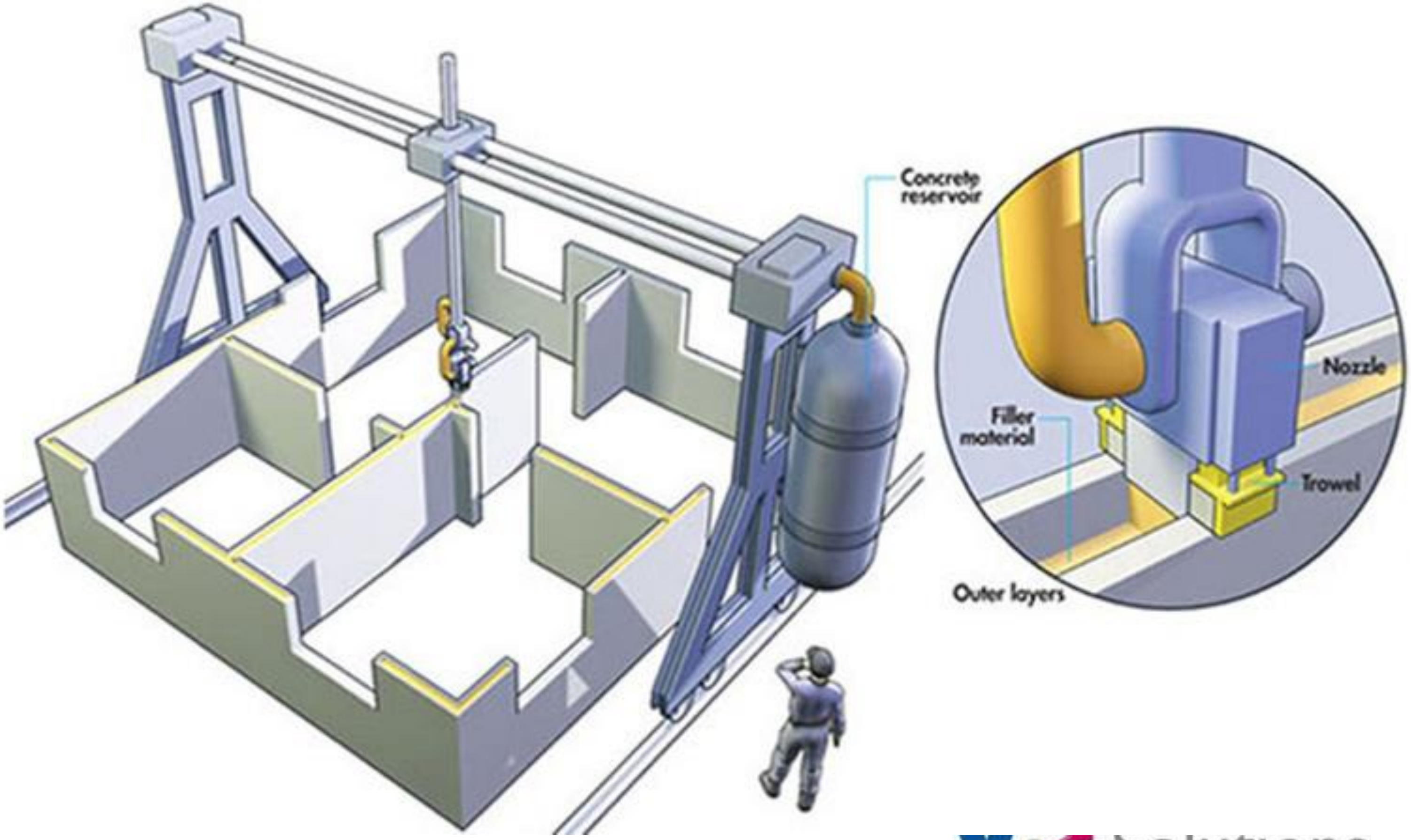
Building Structure Print



- D-Shape: Jets binder into powder
  - Landscape House
  - European Moon housing (Foster & Associates)
- Contour Crafting: Directly deposits cement
  - NASA Moon and Mars housing
- Amsterdam Print Canal House: Fused Deposition Modeling (KamerMaker) of granulated Macromelt bio-plastic from Henkel that is 80% vegetable oil
  - Challenge meeting building codes and installing fireproofing, insulation, foundations and insuring structural integrity
- Slow start

Very Large Nozzle 3D Build

- Behrokh Khoshnevis of Univ. of S California



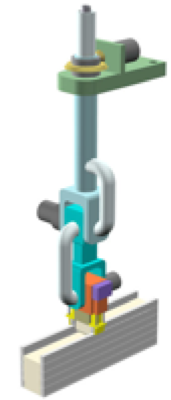


Image source: Contour Crafting

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3D Mansion in China

- WinSun, a Suzhoa, China construction company used XYZ super large funneling to layer concrete material for prefab parts of building
- It built ten 2,100 ft^2 homes Shanghai in a day for $5K per
- Used 4 3D printers:10m wide x 6.6m high depositing fast drying cement

Covers an area of 1,100 square meters (11,840 square feet)

Image source:

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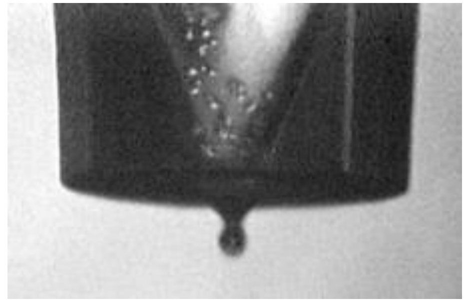
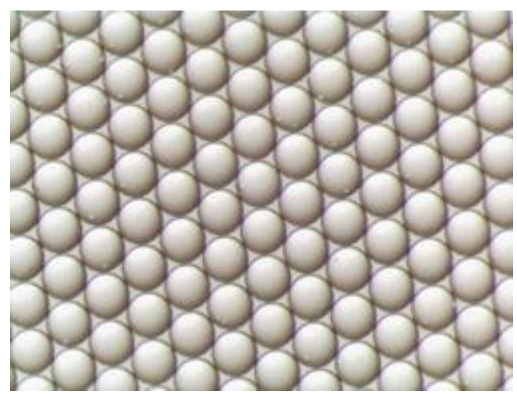
Bio-medical

- MicroFab
  - Biosensors
  - Drug Delivery
  - Dye Assisted Laser Ablation
  - Microarrays
  - Microdispensing
  - Proteomics
  - Solid Microspheres
  - Stents
  - Structural Genomics
  - Tissue Engineering
- Issues: speed & cell viability



Jetting liver cells

Dermal Repair Construct Printer



Jetted microspheres can be loaded with nerve growth factors

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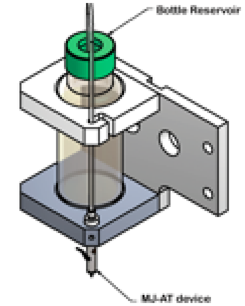
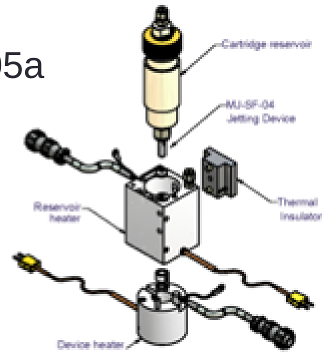
MicroFab

- Low Temperature to 50ºC PIJ DOD: MJ-A
- High Temp. to 250ºC PIJ DOD: MJ-SP
- Fluids < 20cP
- Orifice diameters of 20-80µm available
- Print head assemblies: PH-47, 41, 46, 03, 43, PolymerJet 04a, Solder-Jet 05a

PH-47



PH-05a



- Drop volumes range from 5pl to 0.5nl
- Electronics, displays, medical diagnostics, biomedical, photonics

MJ-A

MJ-SP

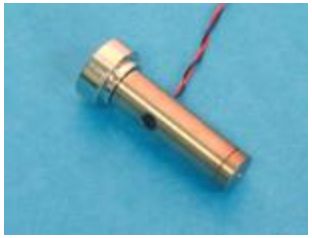


Image source: MicroFab

Microdrop

- MD-K-130: PIJ DOD unheated firing viscosities 0.4-20 cP; nozzle diameters 30µm, 50µm, 70µm
- MD-K-140: PIJ DOD heated nozzle tip firing 0.4-100 cP; nozzle diameters 50µm, 70µm, 100µm

MD-K-130

- MD-K-801: PIJ DOD heated to 160^{o}C nozzle tip, storage bin & hose, firing 0.4-10,000 cP; nozzle diameters 70µm & 100µm

MD-K-801

Image source: Microdrop Technologies

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TNO High Viscosity Inkjet Printer

<u>High Viscosity Inkjet</u>

- Viscosity 20 to 500 mPa•s at room temperature
- 10 to 140 kHz
- Standard head operates at 20 to 80^{o}C
- Modified head can work at 350^{o}C
- High viscosity droplets of 100 µm

Photo Source: TNO

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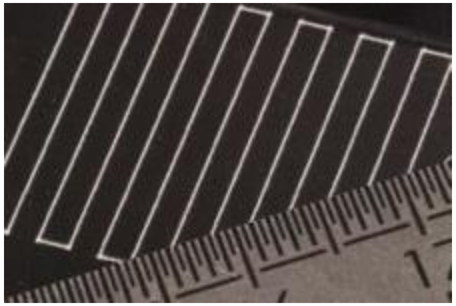
TNO

- Pyrome Printer
- Inkjet print of precursor
- Pyrolysis & melting of metal
- 5µm diameter drop
- Capable of printing very fine electronic circuits



Pyrome Printer

Goldprint

Direct Metal Printing

- MetalPrint/GoldPrint
- Able to inkjet metals with melting up to 1400ºC with 50µm diameter drops

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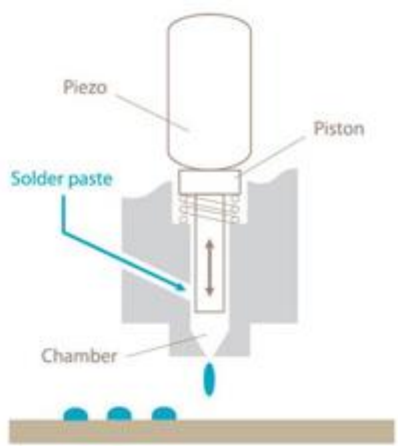
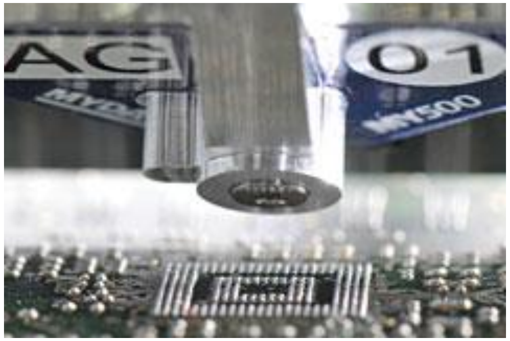
Mycronic AB

- PIJ/screw pump actuated printing of viscous solder paste and SMA (sub-miniature coaxial cable connectors)
- MY600 solder mask jet printer
- Precision 1,080,000 dots/hour





Images source: Mycronic AB

Solutions
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Valve Jet

- Marking & Coding VJ: Domino, Diagraph, Videojet-Marsh
- Dispensing: Liquidyn
- Adhesives, silicones, oils, solder paste, flux (weak acid), lacquers, grease, esters, soapy water (weak alkali), other chemicals
- Viscosities: 0.5-10,000 cP

Liquidyn P-dot CT

Liquidyn P-Dot CT: viscosity: 50-200,000 cP

- Electro-pneumatic
- 3 to 200 nl drop volume
- 350 to 2000µm drop size
- Frequency up to 150 Hz

Essemtec CDS-Jet-DS32

- Up to 1,000 Hz
- 2 to 10,000 nl drops
- Viscosity > 1,200,000 cP


Essemtec Jet Dispensing Valve

Image sources: Liquidyn, Essemtec

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Valve Jet: Techcon

Techcon TS9200D

Techcon Jet Tech Valve TS9200D

- Diaphragm design eliminates fluid seals
- Up to 400,000 cP
- 300 Hz
- Techcon TS9000 Piezo actuated
- 7K to 2 million cP

- TS5400 Needle Valves
- TS1200 Pinch Valves
- TS5000/7000 Rotary Valve Series
- TS5322 & TS941 Spool Valves
- TS 5520 & TS5540 Spray Valves

Valve Jet: Nordson Asymtek

DJ-9500 Jet

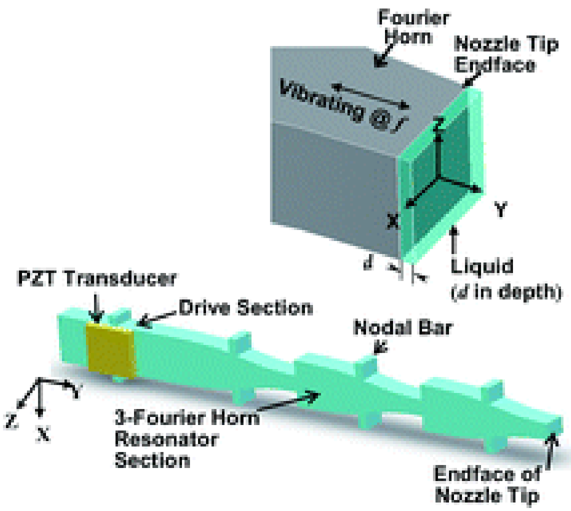
- Orifice Diameter: 0.05 to 1 mm
- Min. drop volume: 1 nl
- Viscosity 1-250k cP
- Drop diameter: 200µm
- Frequency: 200 Hz
- Conductive adhesives & epoxy, adhesives, phosphor filled silicones for bright white LEDs

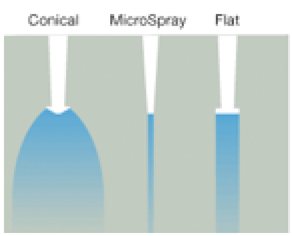
- DJ-2100 DispenseJet
- 83.3 Hz

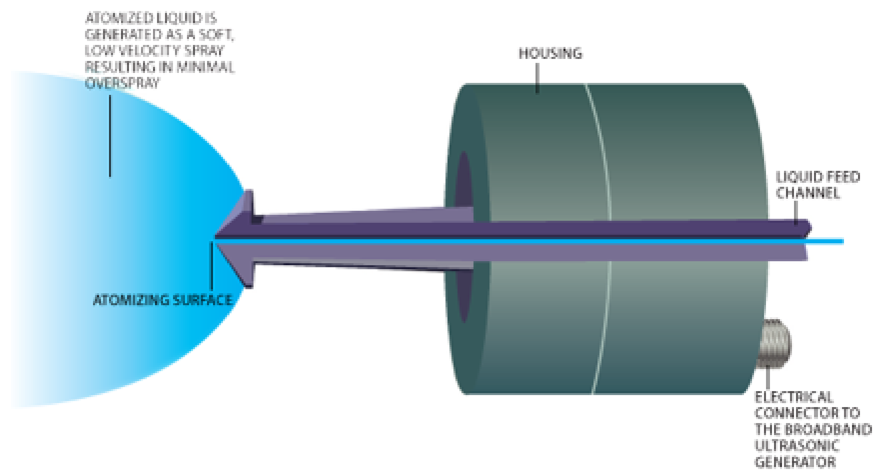
Ultrasonic Droplet Generation

- Piezoelectric transducer generates ultrasound
- Univ. of California, Irvine

- Georgia Tech ejector
- Flatjet: 100 cP
- Sono-tek







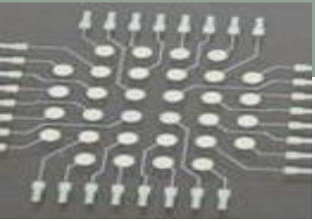
Images source: Sono-tek, Univ. of Calif. Irvine

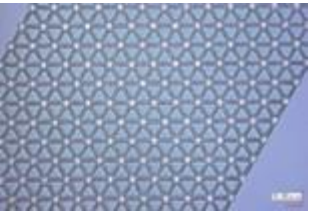
VCE Solutions SPF-INC

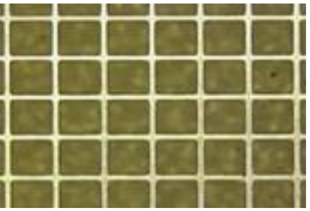
Electrostatic Inkjet

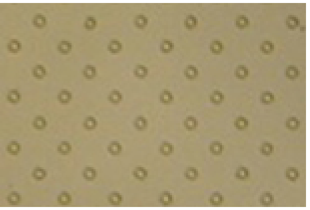
- Electric field induced Taylor cone forms in orifice meniscus
- Concentrate electric force at nozzle (hole type) or pole (pole type)
- Coulomb force generates spray of fine drops
- TTP, NEC, Tokyo Electric, Mathushita
- Tonejet: concentrated pigment ink, droplet volume can vary as desired continuously; beverage cans
- Others: electronic circuits, 3D print, film formation, bio-printing

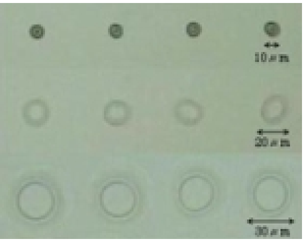
VCE Solutions SPF-INC











SIJ Technology, Inc.

Applications:

- Circuit lines <10μm
- Silver ink 3μm lines
- Gold ink 5μm lines
- Resin ink microlens 10μm diameter
- Protein - albumin
- Micro QR code
- Solar cells, LED, resists, optics, photo masks, touch panels, cell scaffolds, microfilters

- Viscosity: 0.5 to > 10,000 mPa·s (unheated)
- Drop volume: 0.1fl (femto liter) to 10pl (picoliter)
- Precision placement for functional ceramics, electro-conductive polymers, 3D, carbon nanotubes

Image source: SIJ Technology, Inc.

VCE Solutions SPF-INC

Optomec Aerosol Jet

- Pneumatic atomizer handling 1 to 1000 cP
- Standard viscosity <7 cP
- In-line heater & stirrer
- Swappable wide nozzle print head with features from 0.50 mm to 2.0 mm
- Sheath nitrogen gas collimates aerosol
- 200, 300, AJMD 300 & 470 series
- Fine features to 10µm
- Layer deposit =>100nm
- Printed electronics, PV, sensors, biology, touch screens, 3D
- Marathon Series: MSNH, M3NH, M10NH, M3MMWN

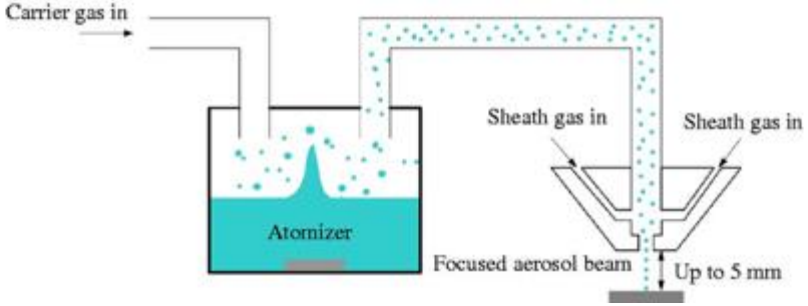


Diagram source: *Sensor Review*, Emerald Group Publishing Limited

VCE Solutions SPF-INC

LIFT Technology

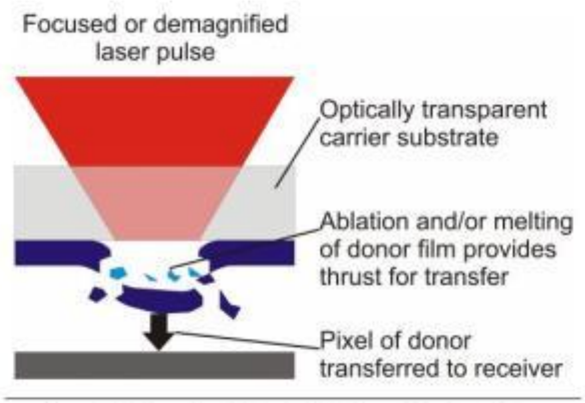
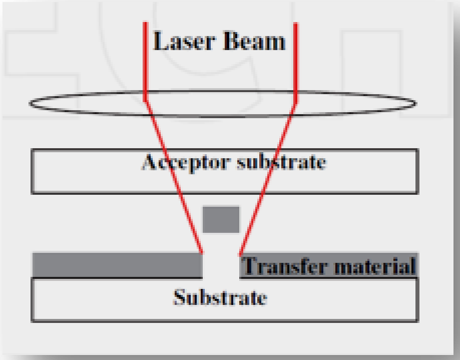


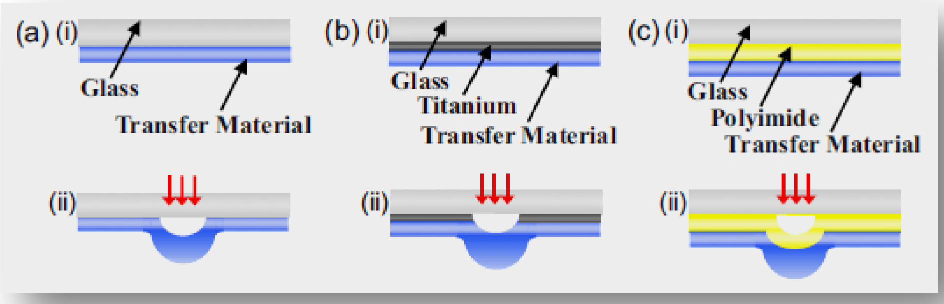
FIGURE 2.1: Illustration of the Laser-Induced Forward Transfer technique.

- Bohandy et al., 1986

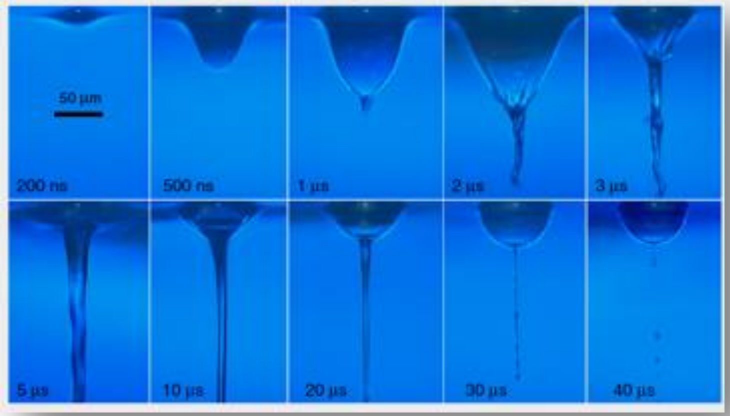
- Rear or Front absorption



- With or without absorbing layer

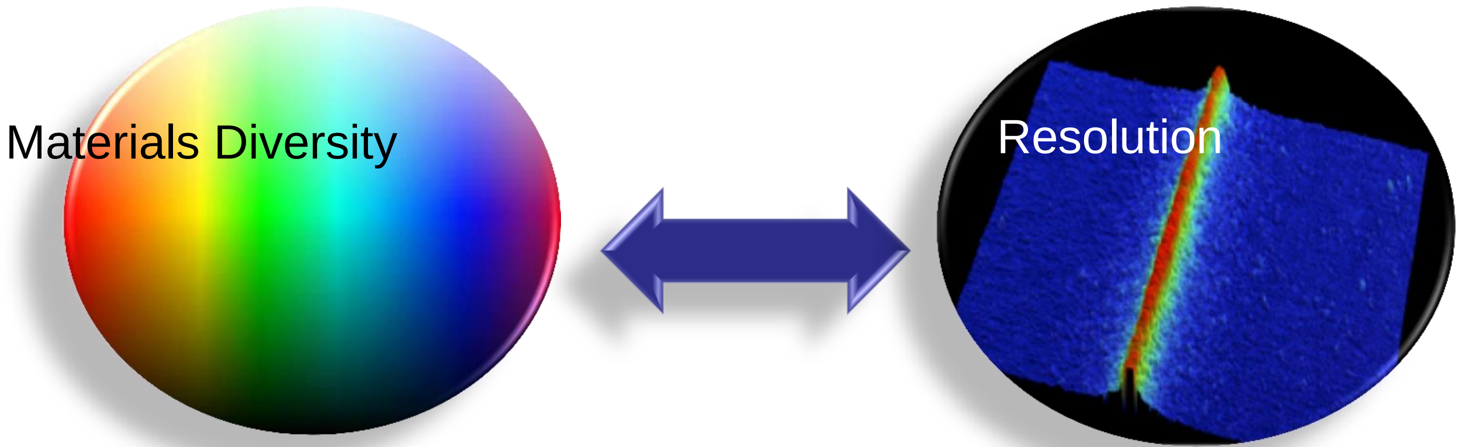


- Solid or Liquid transfer materials



Solutions
SPF-INC

What are the benefits of LIFT?



- Solid materials:
  - Copper, aluminum, ITO …
- Liquid:
  - Metal ink, photoresist, color ink …
- High viscous material:
  - Metal paste, wax, dielectric paste …

- Solid materials:
  - minimal ~3µm average ~10µm
- Liquid & paste:
  - minimal ~10µm average ~20µm
- Dynamic Release Layer (DRL), such as triazene polymer (TP), enables printing of LED, OLED, & wide range of 3D AM materials

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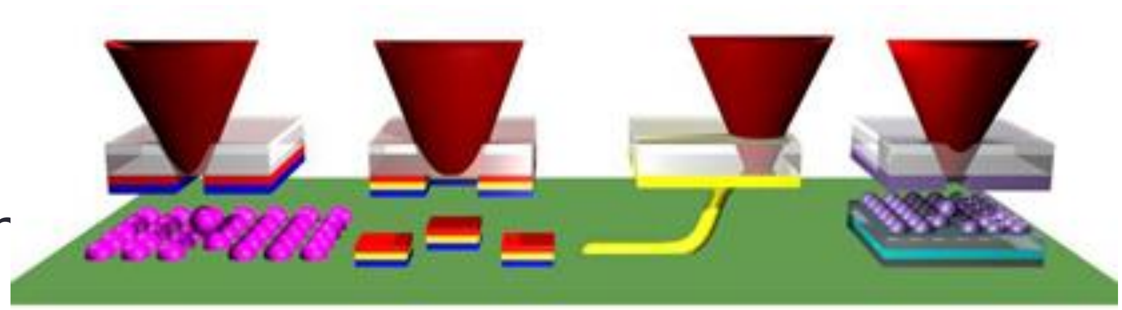
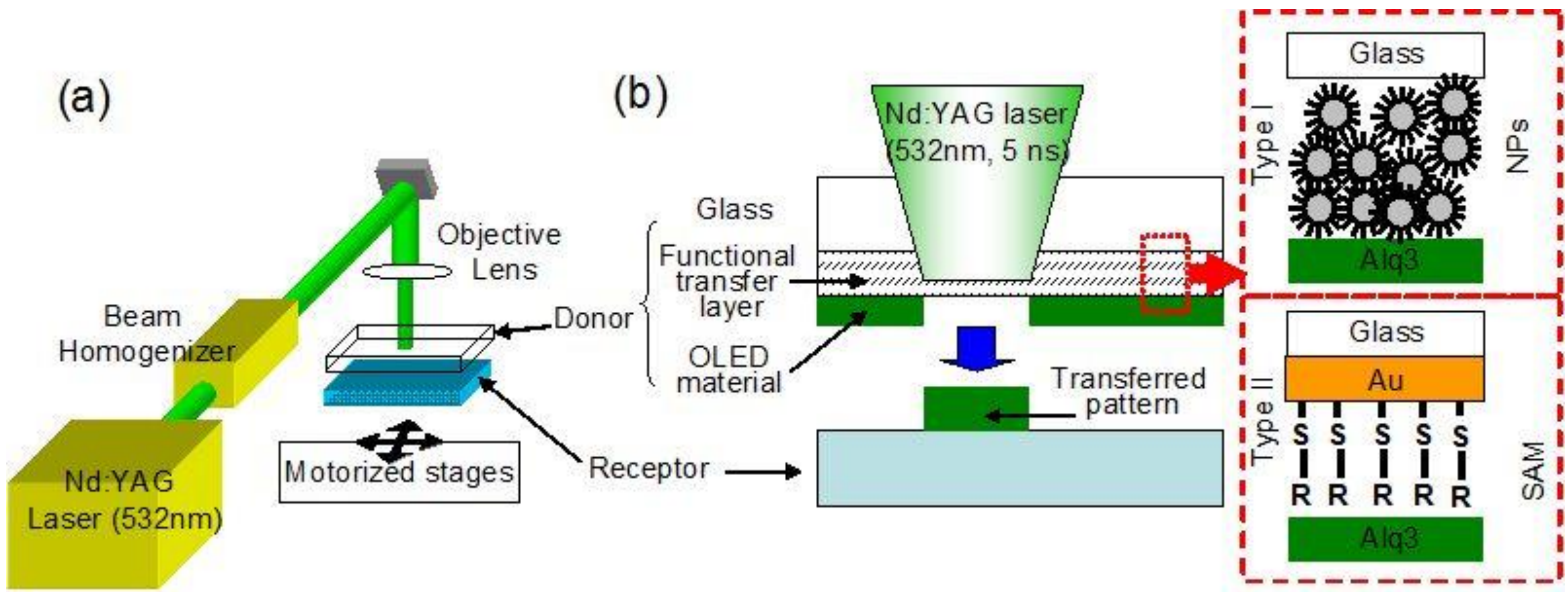
Limitations of LIFT

- Donor preparation
- Material waste
- Laser manipulation
- Donor handling





Photon-Jet 'Donor-less' LIFT

Bio-printing

- Bio inks very viscose – gel formation
- Mechanical stress & heat decrease cell viability
- Single cell resolution
- Max. particle >10μm

- Viscosity 2 to >30,000 cP
- Many advantages of conventional LIFT
- Material 'flow'; no donor preparation
- Little waste material
- No Dynamic Release Layer (DRL) such as triazene polymer (TP)

VCE Solutions SPF-INC

Vince Cahill

- Printer for over 25 years
- Consultant and journalist for over 20 years
- Former CEO of Datametrics, former owner of the Colorworks, Industrial Printing Solutions, Specialty Materials, Newhill Technologies
- Member of the Academy of Screen & Digital Printing Technologies
- President of VCE Solutions, Digital Print & Fabrication Technology and Market Consultancy 717-762-9520

VCE Solutions SPF-INC

Dene Taylor, PhD

- Over 20 years of experience with technical leadership & product & process development of printing, coating, packaging & material solutions
- Formed SPF-Inc in 2000 serving clients internationally
- Established DECSTEC in 2001 and served as CEO and CTO after its sale
- Prior employers include Union Camp (now part of International Paper), Mead Paper, James River Corp., Rexam & Dunmore
- Holds many patents, some assigned to clients & former employers

Thank You

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