IFM Briefing day
13 May 2014

Industrial inkjet technology

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Scope of talk

- how ink-jet printing works and some research challenges
- examples of our recent research

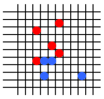
Printing processes

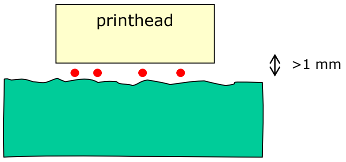
- Conventional printing
  - all processes use a durable matrix/plate which is used to transfer ink to a substrate
  - involves contact with substrate
  - ideal for producing large numbers of identical copies
- Ink-jet printing
  - ink is delivered in individual droplets to the substrate
  - non-contact process
  - can print a sequence of identical or completely different products
  - completely flexible, digital process

Key features of inkjet printing

It is a **digital** process – the location of each droplet of ink can be accurately positioned on a grid, under computer control

Patterns can be varied immediately between or even within individual products

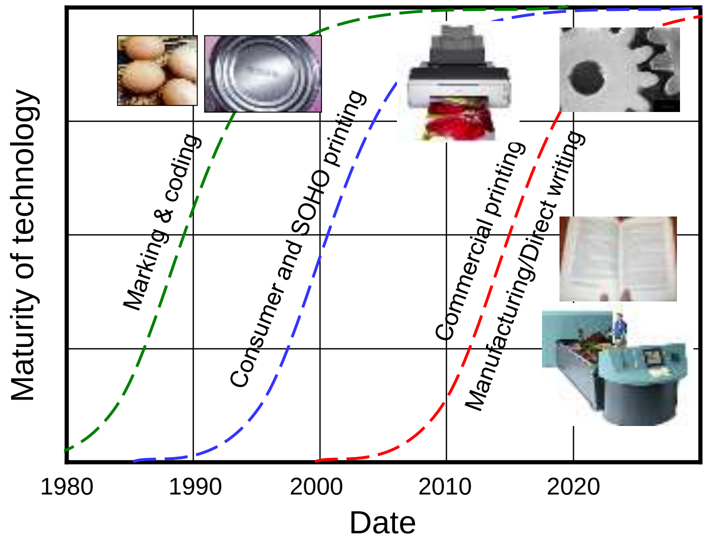




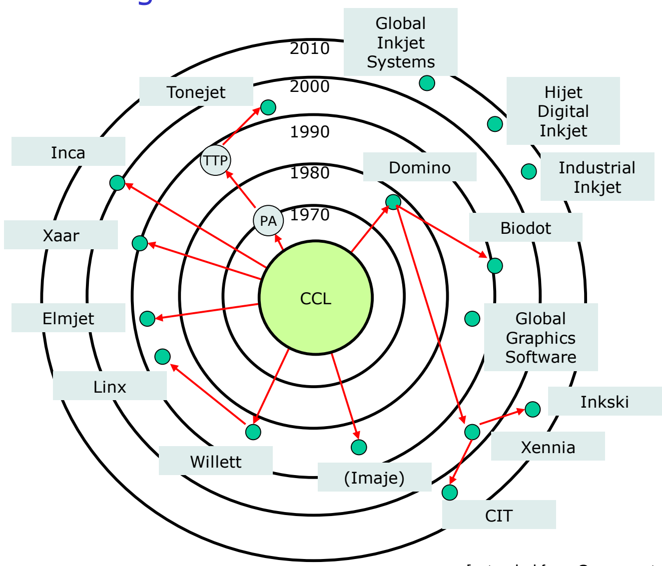
It is a **non-contact** method and so can be used to print on surfaces which are not flat, and also for fragile surfaces

A **wide range of materials** can be deposited.

The only limitation is that they must be in liquid form at the time of printing.



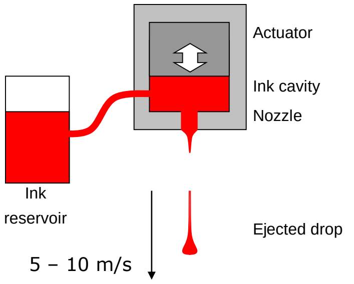
The Cambridge cluster

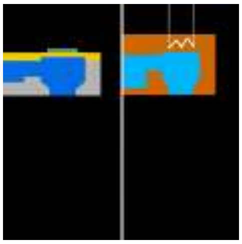


[extended from Garnsey et al. 2009]

Drop-on-demand printing: principles

- Each drop (typically 20 – 50 µm diameter) is produced in response to an electrical signal to an actuator in the nozzle chamber
- The printhead contains a large number (hundreds) of separately addressable nozzles
- There are two common types of actuator: thermal and piezo-electric



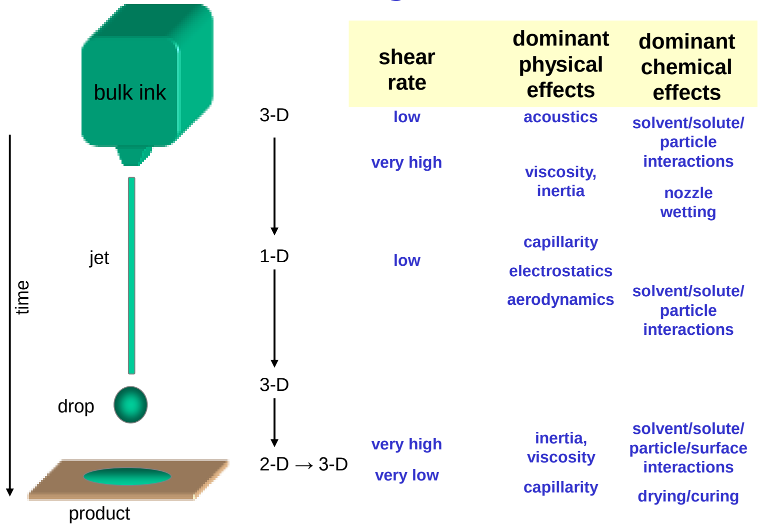


Drop-on-demand: industrial piezoelectric printhead

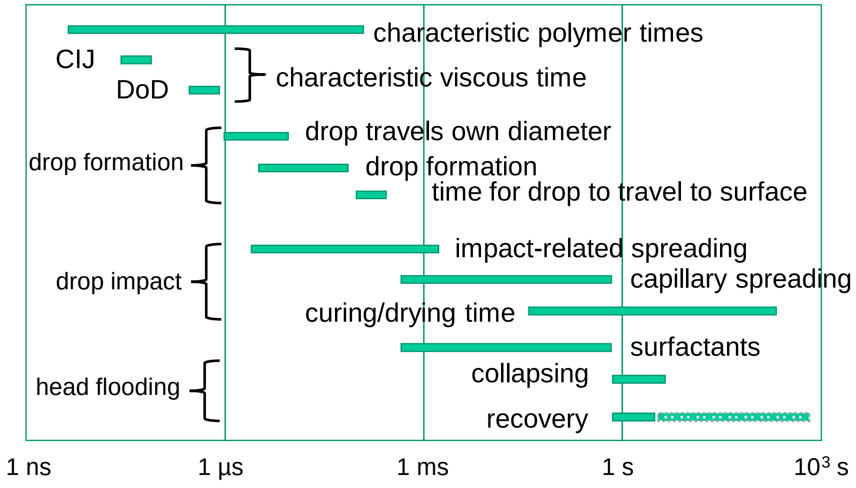
- Example of a modern drop-on-demand industrial printhead:
- 1000 nozzles over 70 mm length i.e. 70 µm spacing
- ~10^4 drops per second emitted from each nozzle
- variable drop volume 6-42 pL (= 22-43 µm diameter)

[Image: Xaar]

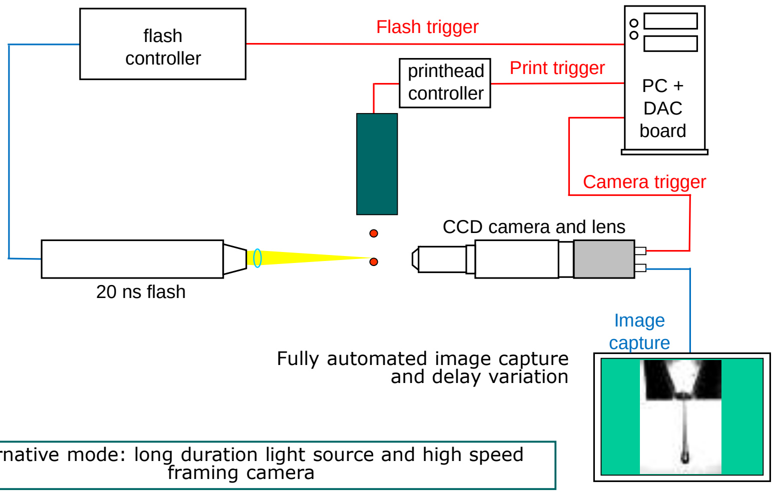
Some technical challenges



Timescales in inkjet printing

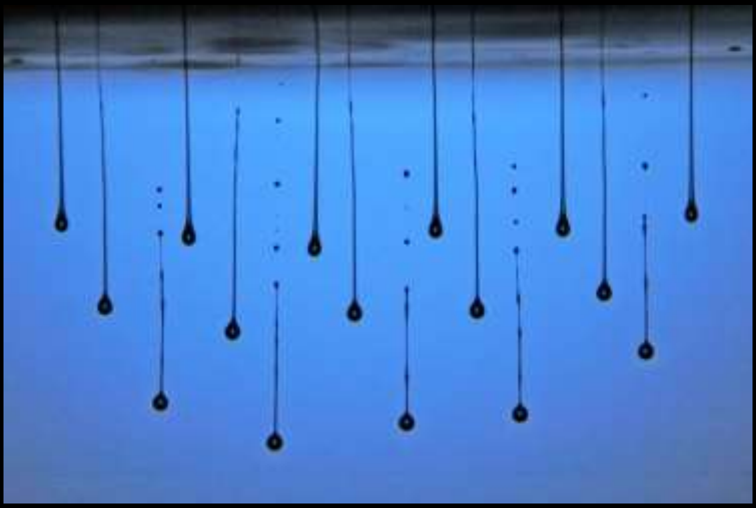


Jet imaging rig



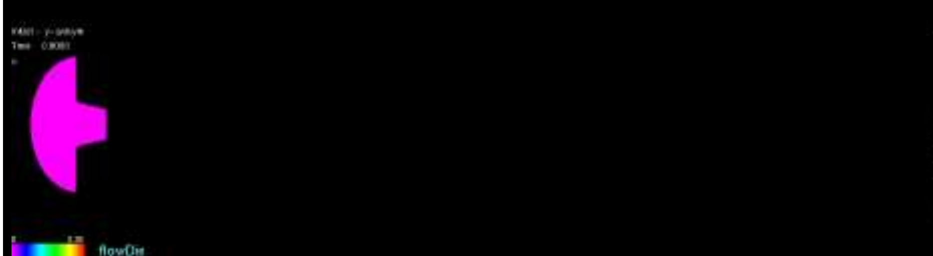
Alternative mode: long duration light source and high speed framing camera

Single-flash image: 20 ns duration



Pseudo-sequence of images

Modelling of fluid flow in jet formation



Lagrangian FE model for viscoelastic flows (multiple modes) with inertia & free surfaces

Mesh adaptivity to handle thin filaments & droplet break-off

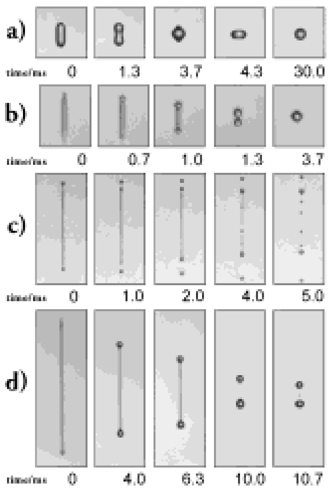
(Harlen, Yarlanki and Morrison, University of Leeds)

Breakup of liquid filaments

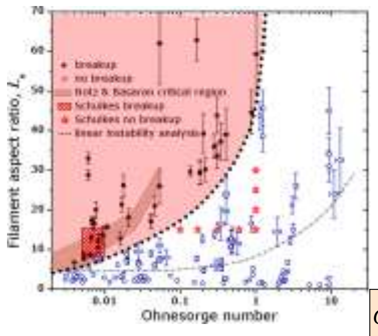
What controls whether a thin filament of liquid separates into two or more droplets or condenses lengthwise to form a single drop?

[Castrejon-Pita et al., Phys Rev Lett. **108** (2012) 074506]

Breakup of liquid filaments

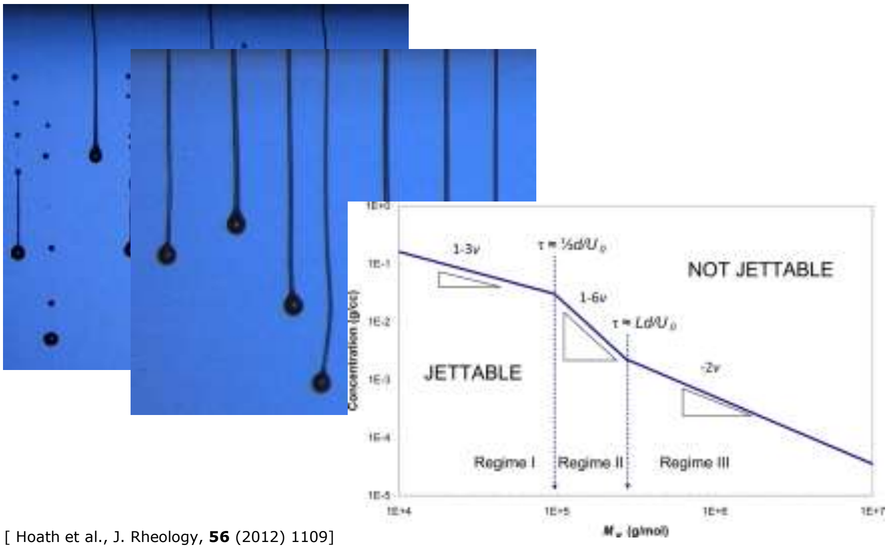


Breakup is controlled by the initial dimensions of the filament and the liquid properties: density, viscosity, and surface tension



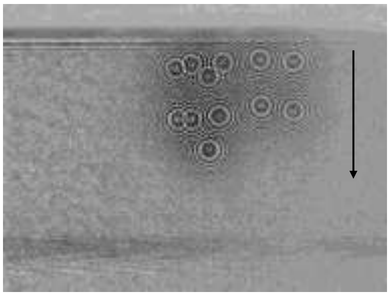
$$Oh = \frac{\eta}{\sqrt{\rho \sigma R_o}}$$

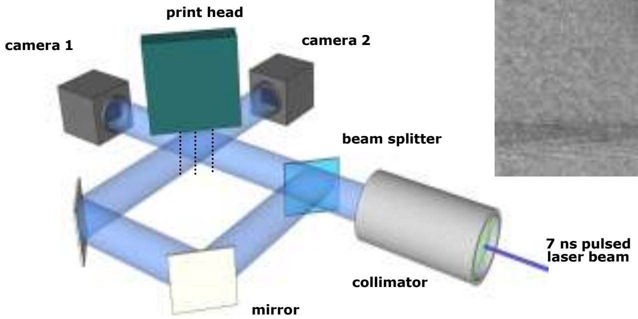
Elastic effects due to polymers in ink



[Hoath et al., J. Rheology, **56** (2012) 1109]

High-speed holography for ultra-precise measurements of drop size and position

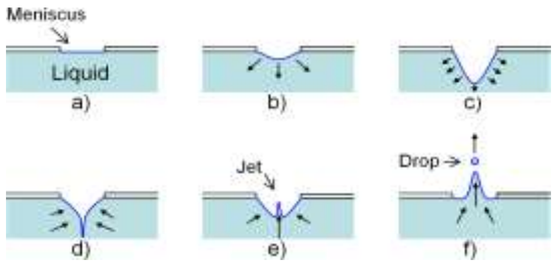


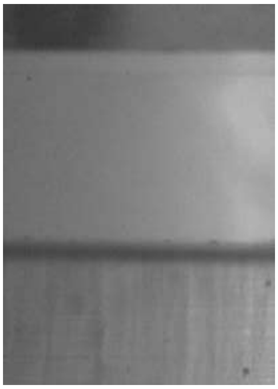


Typical accuracy in measurement of position (x, y, z) and drop radius ±0.3 µm

[Martin et al., Proc. NIP27 (2011) 620-623]

CADET – a new method for generating small drops



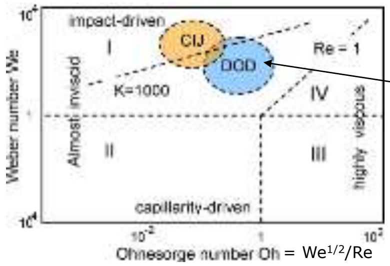


[Castrejon-Pita et al., Rev Sci Inst, 83 (2012) 115105]

Drop impact

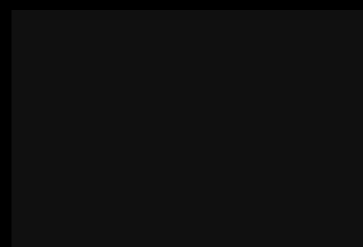
- What happens when a liquid drop hits a surface depends on the relative effects of inertia, viscous and surface tension forces – which can be described by the Reynolds and Weber numbers

$$Re = \frac{\rho V D}{\mu} \qquad We = \frac{\rho V^2 D}{\sigma}$$



Splashing does not occur for typical drop-on-demand conditions – it is favoured by a larger drop, higher impact speed, lower surface tension, lower viscosity or a rough substrate

Modelling of drop impact: heterogeneous surface



Water drop, 2 mm diameter, 1 m/s
Numerical model based on level set method:
linear viscous fluid with surface tension and gravity
Simulation: Kensuke Yokoi
Experiment: Damien Vadillo, CU Dept of Chemical Engineering

Effect of print frequency/spacing on drop merging

Print frequency: 398 Hz

Effect of print frequency/spacing on drop merging

Print frequency: 429 Hz

Drop merging/mixing

[Castrejon-Pita et al., Phys Rev E **88** (2013) 023023]

Drop merging/mixing

Drop merging/mixing

Applications of inkjet in manufacturing

NOW

- Additive manufacturing: polymers
- Fabrics, wallpapers, laminates
- Passive electronic components
- Additive manufacturing: metals, ceramics
- Active electronic components
- Optics: lenses, waveguides
- Biomedical devices: lab-on-a-chip, diagnostic arrays
- Sensors: acoustic, thermal, mechanical, optical, bio
- Smart materials: integrated sensors, transducers
- Tissue synthesis: artificial skin, bone, organs

FUTURE
- ……………………………………………………………….

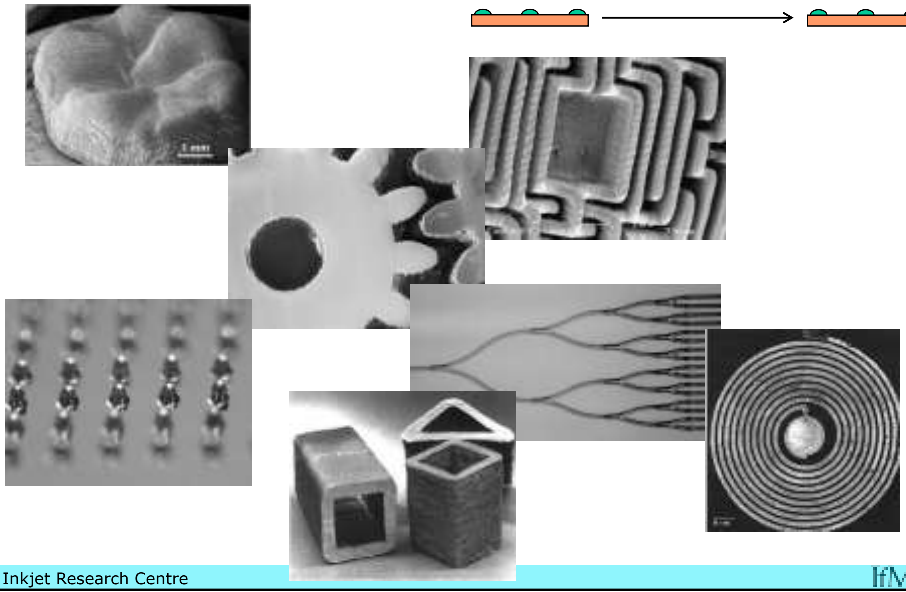
Inkjet-based additive manufacturing (3D printing)

[Gartner's 2013 Hype Cycle for Emerging Technology]

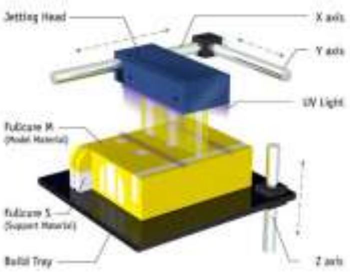
Inkjet-based additive manufacturing (3D printing)

- Direct material printing
  - polymer
  - ceramic
  - metal
- Printing on to powder bed

Direct material printing

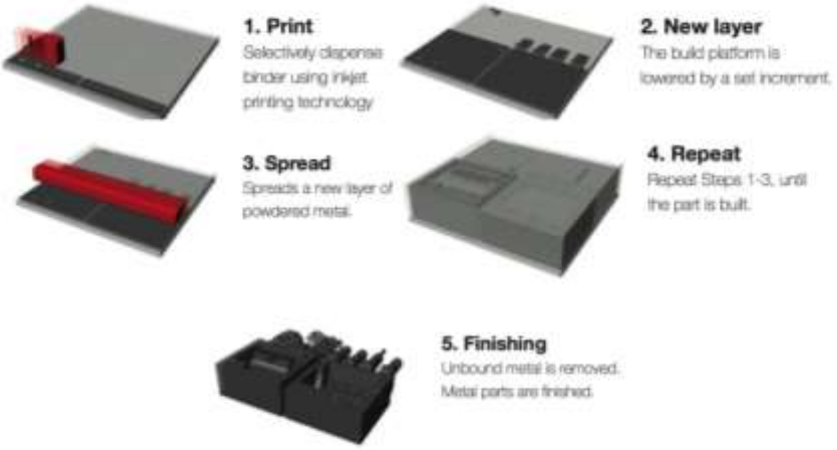


Direct material printing (e.g. Stratasys/Objet)



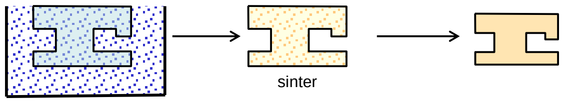
(commercial systems limited to polymers and waxes)

Printing on to metal powder bed



[Prometal Inc.]

Printing on to metal powder bed



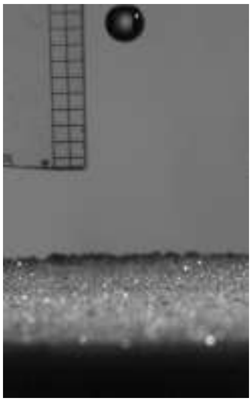
print binder on to
powder bed

stainless steel, Ti, tool steel
resolution 35 μm
surface finish RA = 4 μm

[Höganas, Sweden]

Initial experiments to study droplet impact on to powder beds – effects of wettability

Impact of 1.2 mm diameter water drop at 0.7 m s^{-1}

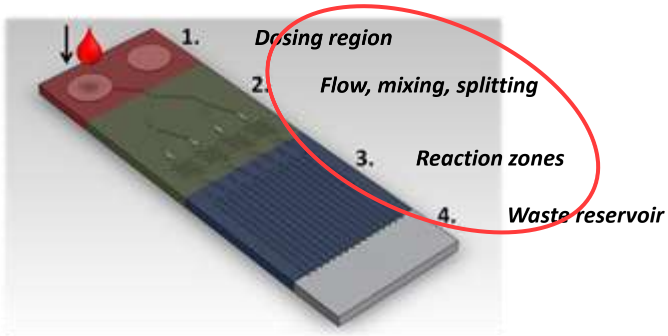


200-300 μm glass beads

200-300 μm polystyrene beads

Inkjet & biosensors

- **Flexible manufacturing** methods to make diagnostic sensors
- **Reconfigurable** and customisable at the point of manufacture.
- **Platform** capable of different diagnostic test functions.
- Potential for simultaneous **multi-analyte** testing.



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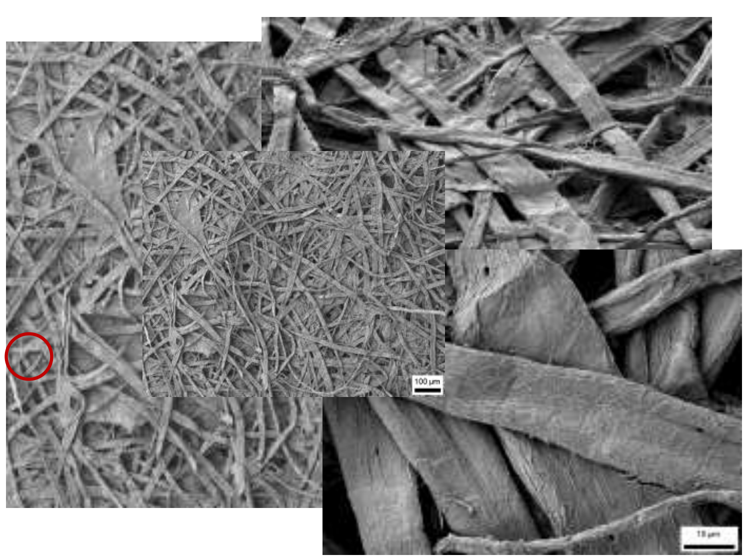
Inkjet for flow programming in paper-based devices

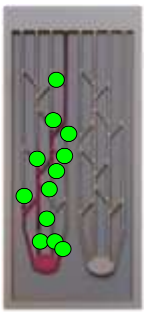


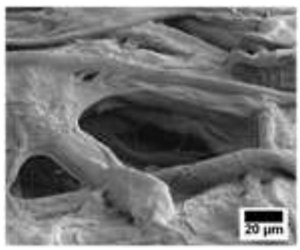
Inkjet Research Centre IfM

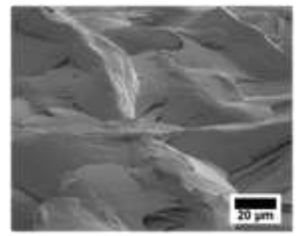
Flow programming in paper-based devices: two methods

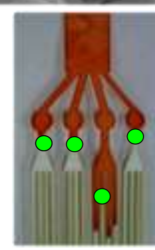
Completely block the capillaries

Treat surface to change surface energy



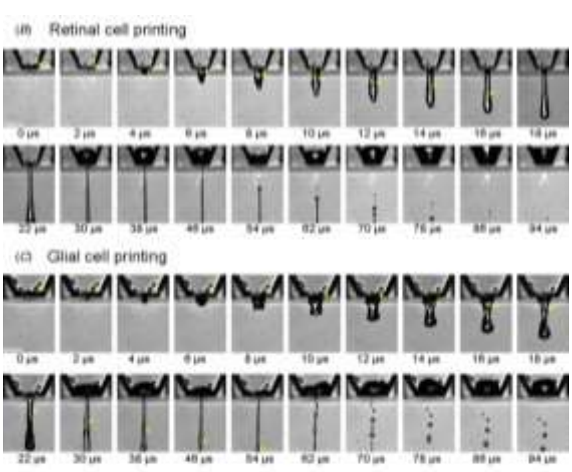


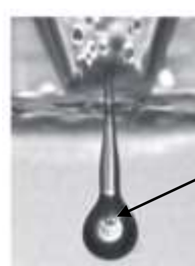




examples of laser-cut paper channels, 0.8 mm wide

Inkjet printing of living cells





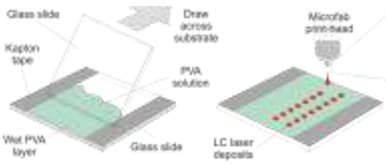
Retinal cells in fluid jet

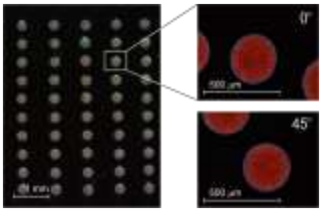
Working with colleagues in the Department of Clinical Neurosciences at Cambridge, we have investigated survival of mammalian retinal cells during inkjet printing – an essential step to future use in regenerative medicine.

[Lorber, et al Biofabrication, *6*, **2014**, *015001*]

Inkjet printing of liquid crystal laser arrays

Working with colleagues in the Centre of Molecular Materials for Photonics and Electronics at Cambridge, we have investigated inkjet printing of single drops of liquid crystal polymer mixture on to a wet PVA film.

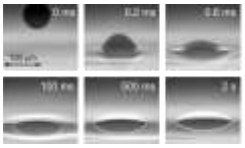


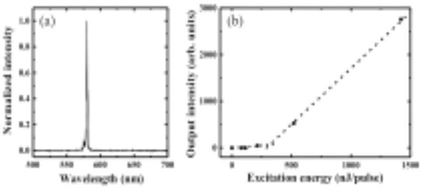


Laser dot arrays pumped at 532 nm showed clear single-mode lasing with a linewidth less than 1 nm.

A full ink-jet process route is possible, with potential applications in security devices, sensors and other fields.

The PVA constrains the LC region and as it dries induces molecular alignment leading to high-quality laser action.





[Gardiner et al., Soft Matter **8**, 9977 (2012)]

Our expertise and research interests

- high speed, high resolution optical imaging by conventional and holographic methods
- diagnostic techniques for external and internal liquid flows including LDV and PIV
- generation and behaviour of liquid jets and drops, from both continuous and drop-on-demand inkjets
- fundamental fluid mechanical phenomena in jets and drops
- drop impact on non-porous and porous surfaces
- wetting and dewetting
- liquid penetration into porous and fibrous media
- drop merging and mixing
- effects of complex rheology
- inkjet as a tool for manufacturing, including additive manufacturing, microfluidics and bio-applications

Inkjet Interest Group

6-monthly evening meetings - presentations plus dinner

Next meeting: 26 June 2014

We are always glad to discuss opportunities for collaboration

e-mail: imh2@cam.ac.uk

Further information:
www.ifm.eng.cam.ac.uk/research/irc/