IFM Briefing day
21 May 2013

Innovation in industrial inkjet technology

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Scope of talk

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

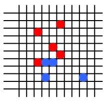
Printing processes

- 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

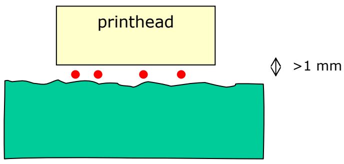
Key features of inkjet printing

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

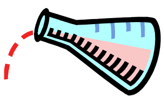


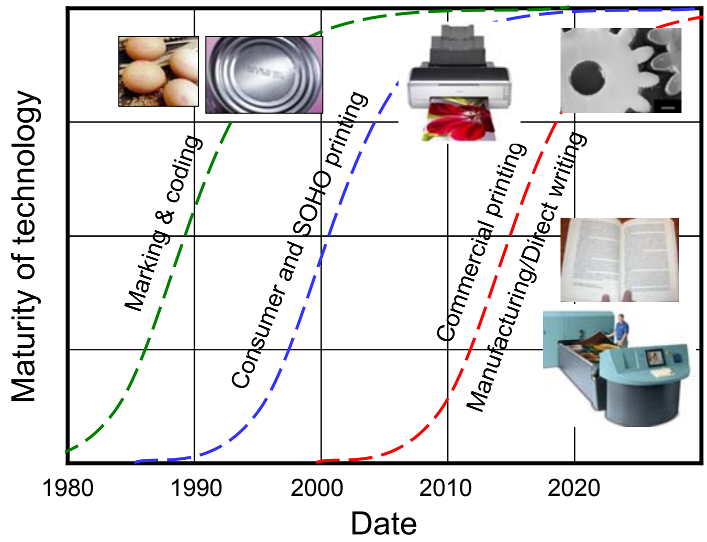
It is a **non-contact** method and so can be used to print on surfaces which are not flat, and also for fragile surfaces



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

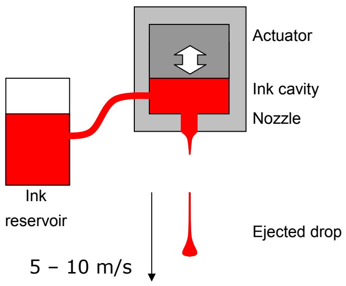
The only limitation is that they must be in liquid form at the time of printing.

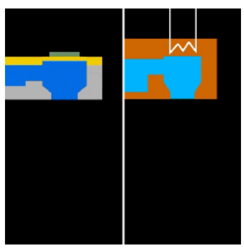




Drop-on-demand printing: principles

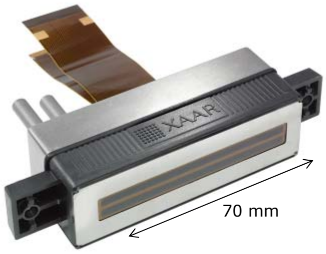
- Each drop (typically 20 – 50 µm diameter) is produced in response to an electrical signal to an actuator in the nozzle chamber
- The printhead contains a large number (hundreds) of separately addressable nozzles
- There are two common types of actuator: thermal and piezo-electric





A modern industrial piezoelectric drop-on-demand printhead

- 1000 nozzles over 70 mm length i.e. 70 μm spacing
- ~10^4 drops per second emitted from each nozzle
- capable of printing 130 m^2 per hour
- variable drop volume 6-42 pL (= 22-43 μm diameter)

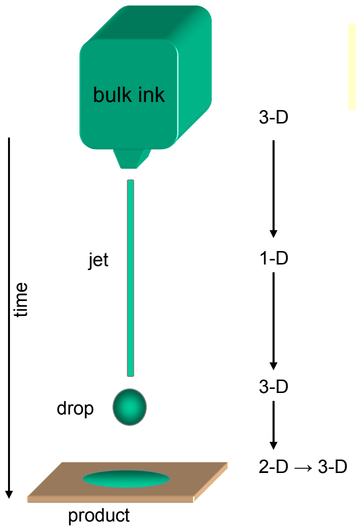


[Image: Xaar]

42×10^{-12} litres x 1000 nozzles x 6 kHz ≈ 1 tonne per year

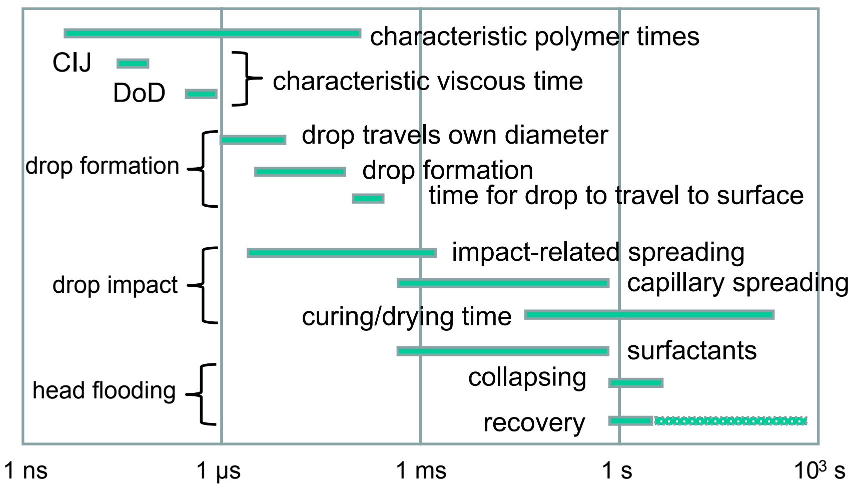
Ink-jet printing provides a method for the controlled and accurate deposition of multiple materials in potentially large volumes

Some technical challenges

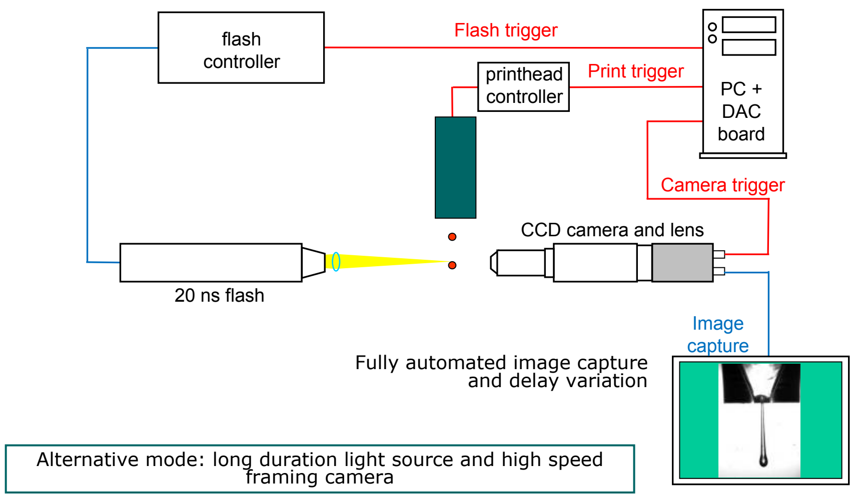


shear rate	dominant physical effects	dominant chemical effects
low	acoustics	solvent/solute/particle interactions
very high	viscosity, inertia	nozzle wetting
low	capillarity electrostatics aerodynamics	solvent/solute/particle interactions
very high very low	inertia, viscosity capillarity	solvent/solute/particle/surface interactions drying/curing

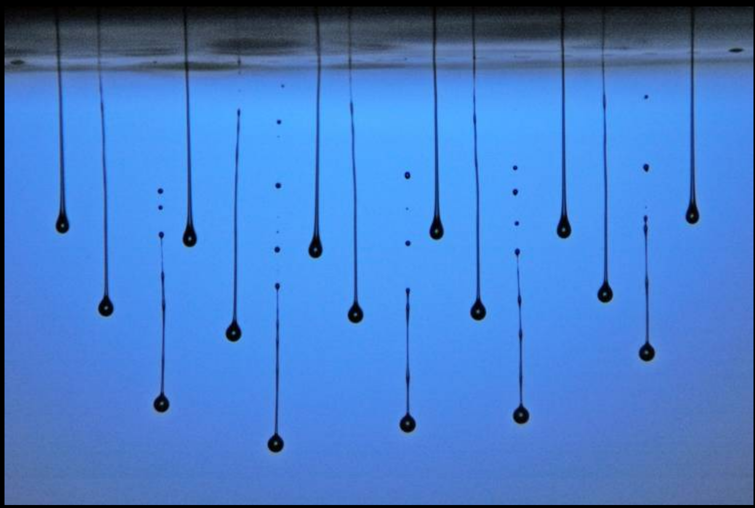
Timescales in inkjet printing



Jet imaging rig



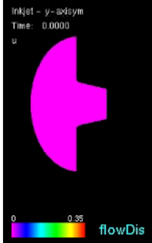
Single-flash image: 20 ns duration



400 µm

Pseudo-sequence of images

Modelling of fluid flow in jet formation



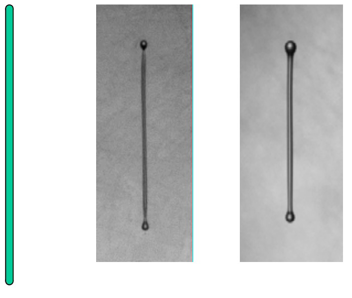
Lagrangian FE model for viscoelastic flows (multiple modes) with inertia & free surfaces

Mesh adaptivity to handle thin filaments & droplet break-off

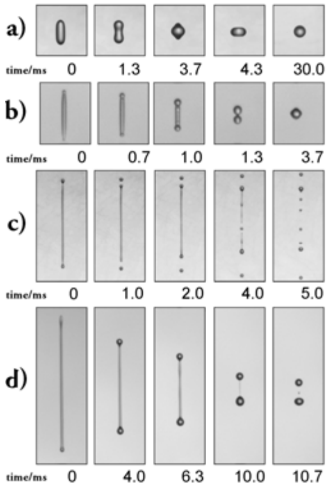
(Harlen, Yarlanki and Morrison, University of Leeds)

Breakup of liquid filaments

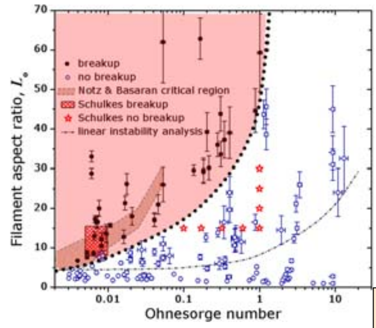
What controls whether a thin filament of liquid separates into two or more droplets or condenses lengthwise to form a single drop?



Breakup of liquid filaments

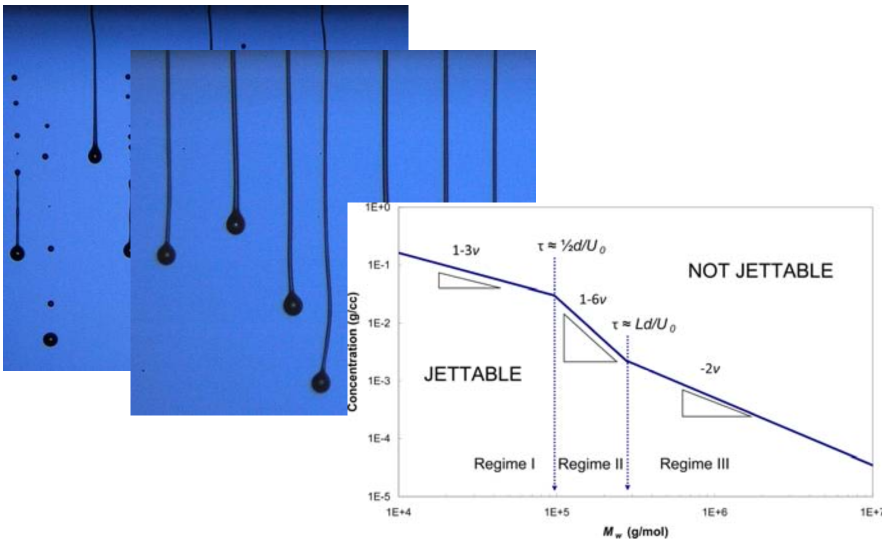


Breakup is controlled by the initial dimensions of the filament and the liquid properties: density, viscosity, and surface tension

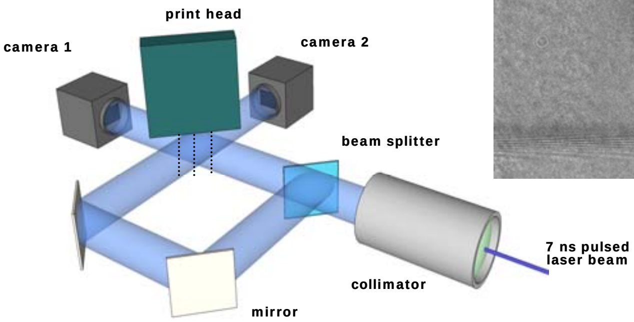


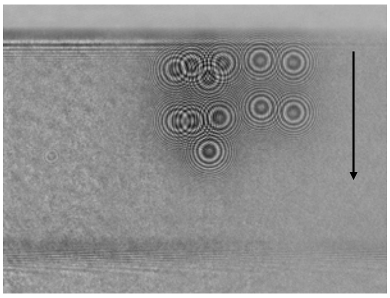
$$Oh = \frac{\eta}{\sqrt{\rho \sigma R_0}}$$

Elastic effects due to polymers in ink



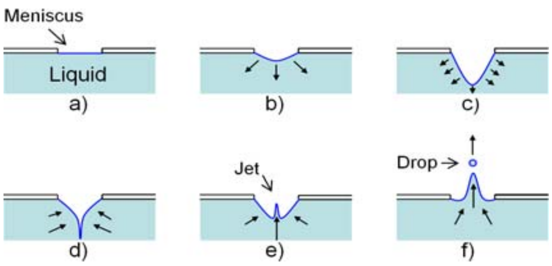
High-speed holography for ultra-precise measurements of drop size and position

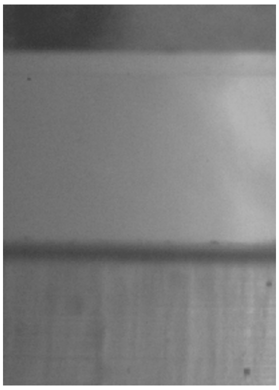




Typical accuracy in measurement of position (x, y, z) and drop radius ±0.3 μm

CADET – a new method for generating small drops





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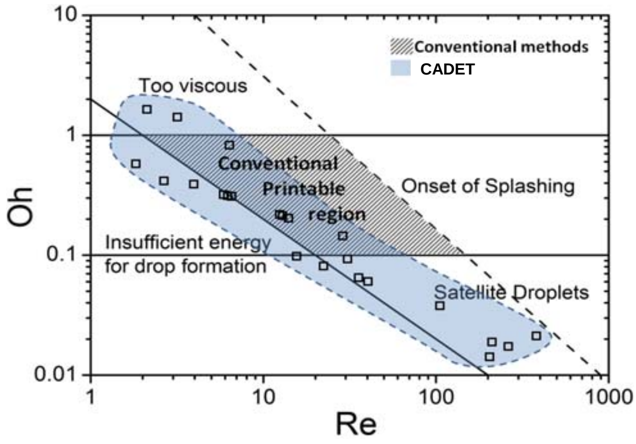

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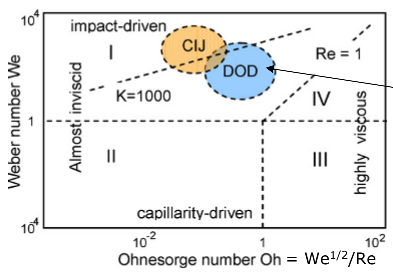
Drop impact

- 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

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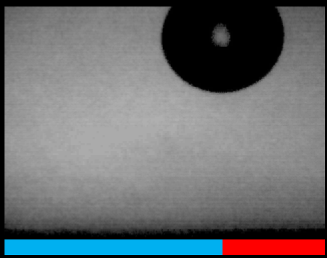
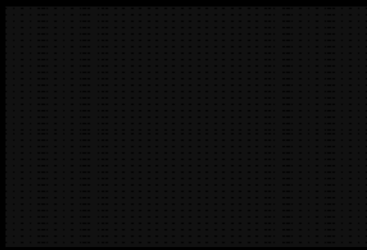
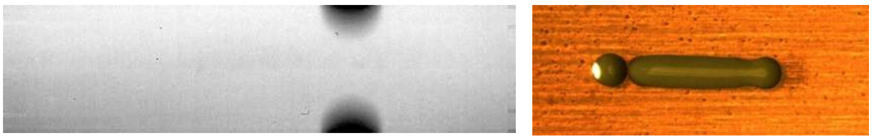
Modelling of drop impact: heterogeneous surface



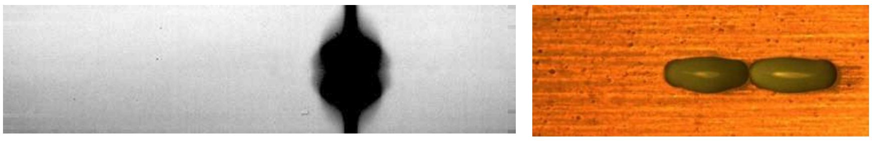


Water drop, 2 mm diameter, 1 m/s
Numerical model based on level set method:
linear viscous fluid with surface tension and gravity
Simulation: Kensuke Yokoi
Experiment: Damien Vadillo, CU Dept of Chemical Engineering

Effect of print frequency/spacing on drop merging

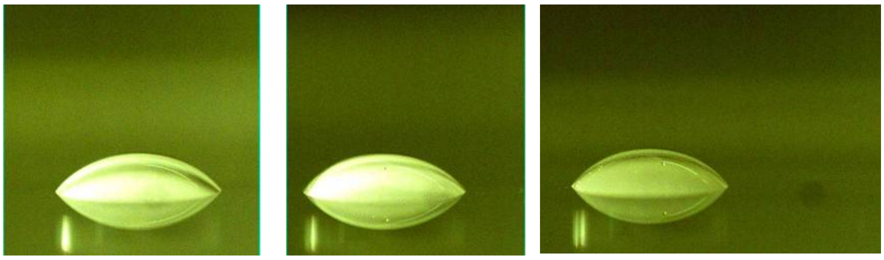


Print frequency: 398 Hz

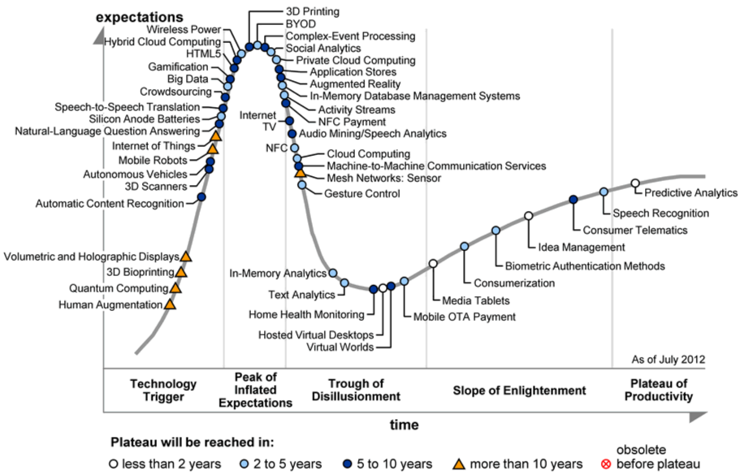


Print frequency: 429 Hz

Drop merging/mixing



Inkjet-based additive manufacturing (3D printing)



[Gartner's 2012 Hype Cycle for Emerging Technology]

Inkjet-based additive manufacturing (3D printing)

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

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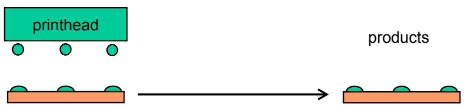
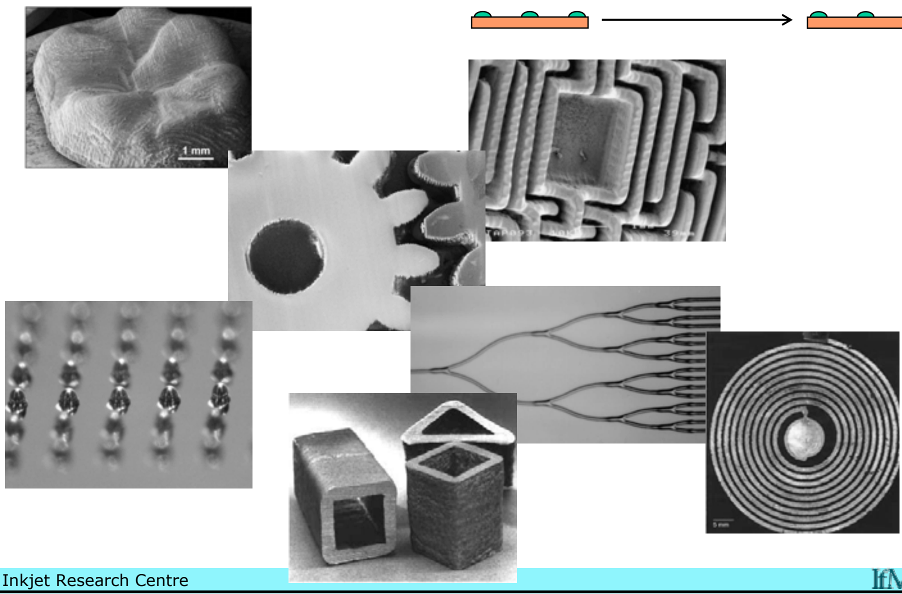
Direct material printing





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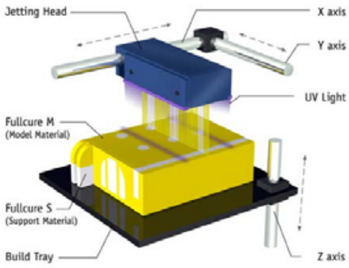
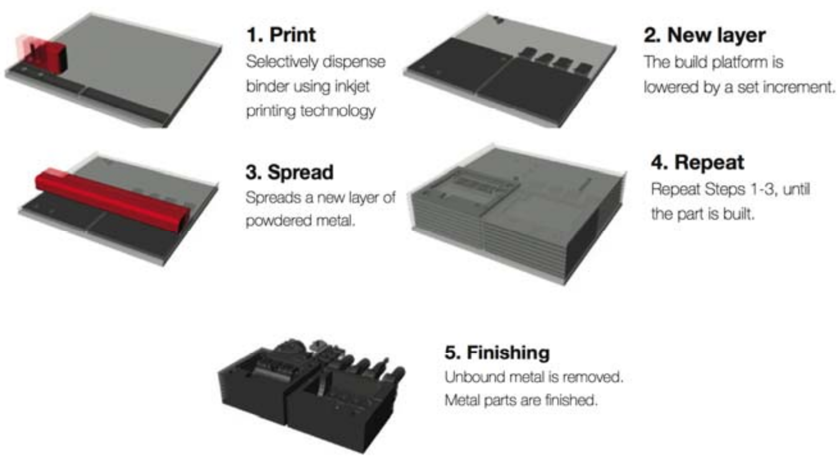
Direct material printing (e.g. Stratasys/Objet)



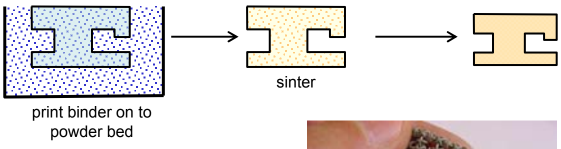
(commercial systems limited to polymers and waxes)

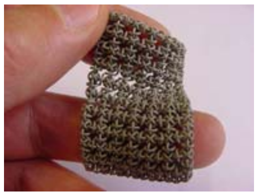
Printing on to metal powder bed



[Prometal Inc.]

Printing on to metal powder bed



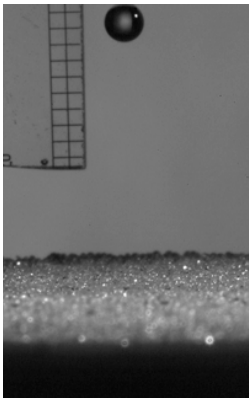


stainless steel, Ti, tool steel
resolution 35 µm
surface finish RA = 4 µm

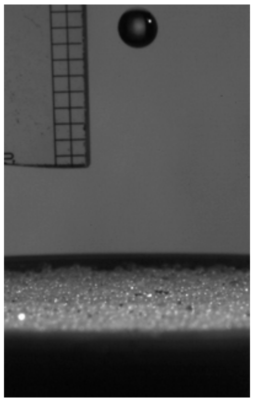
[Höganas, Sweden]

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



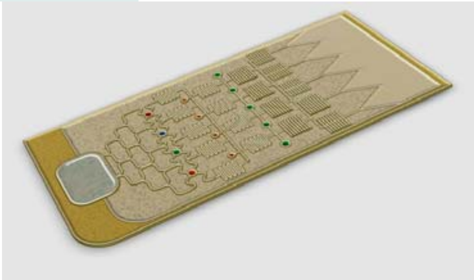
200-300 µm polystyrene beads

BiognostiX

FP7

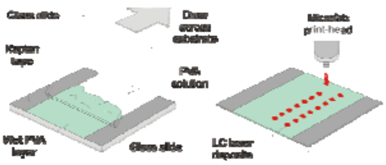
Objective: to develop a new industrial manufacturing process for customised fabrication of diagnostic sensors on fibre-based substrates.

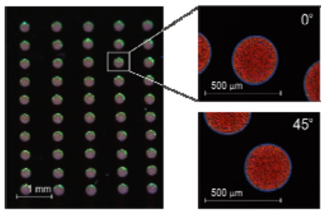
Inkjet printing is being used to:
•create patterned substrates, and
•dispense functional components for bioassay



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.

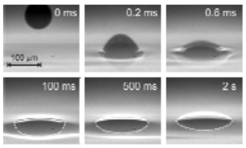


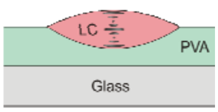


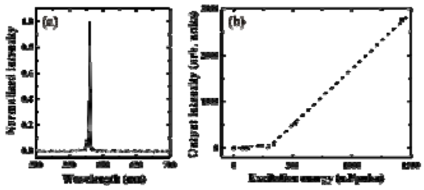
Laser dot arrays pumped at 532 nm showed clear single-mode lasing with a linewidth less than 1 nm.

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.







Inkjet Interest Group

6-monthly evening meetings
presentations plus dinner

Next meeting: 6 June 2013

- published December 2012
- 15 chapters
- 370 pages

We are always glad to discuss opportunities for collaboration
e-mail: imh2@cam.ac.uk

Further information:
www.ifm.eng.cam.ac.uk/pp/inkjet