Industrial inkjet technology

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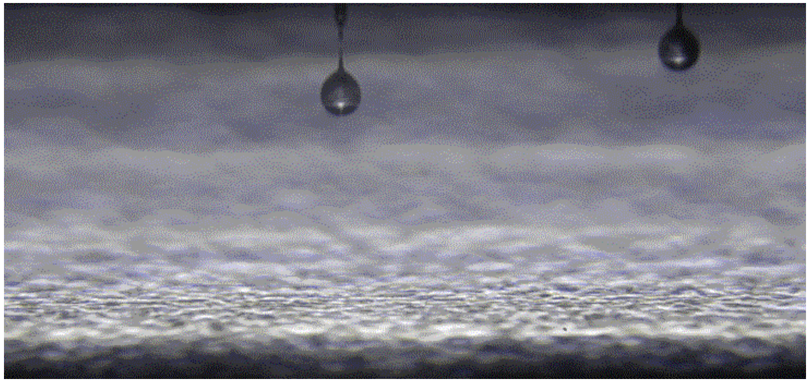
Scope of talk

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

Printing processes

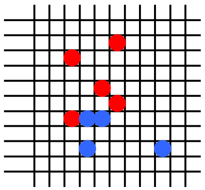


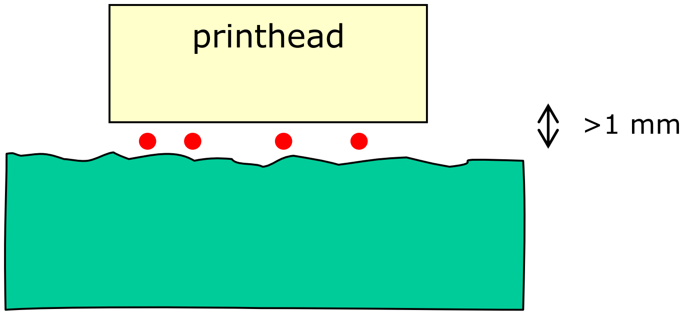
- Conventional printing
  - all processes use a durable matrix/plate which is used to transfer ink to a substrate
  - involves contact with substrate
  - ideal for producing large numbers of identical copies
- Ink-jet printing
  - ink is delivered in individual droplets to the substrate
  - non-contact 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

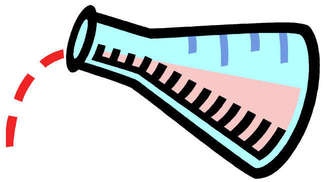


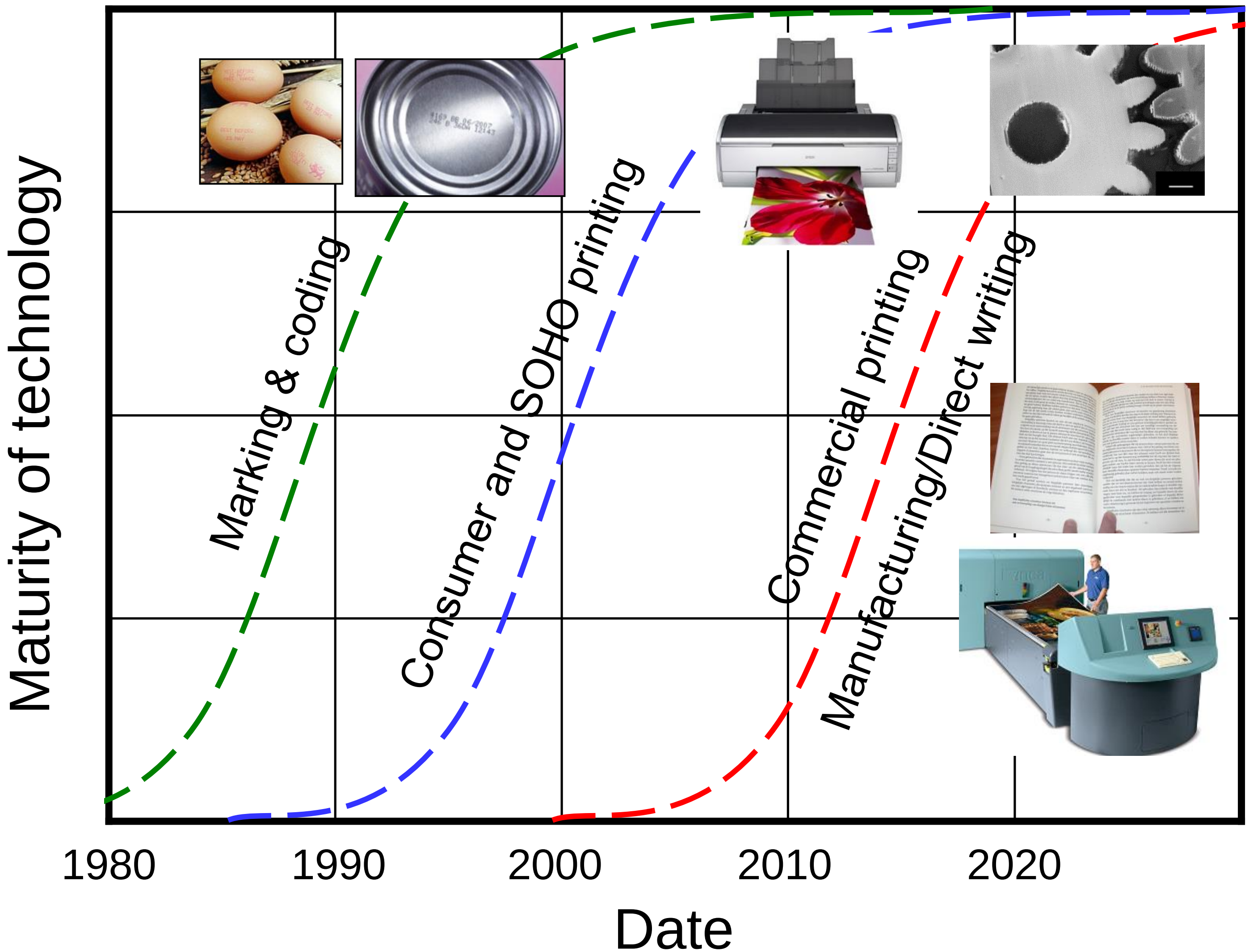


It is a **non-contact** method and so can be used to print on surfaces which are not flat, and also for fragile surfaces

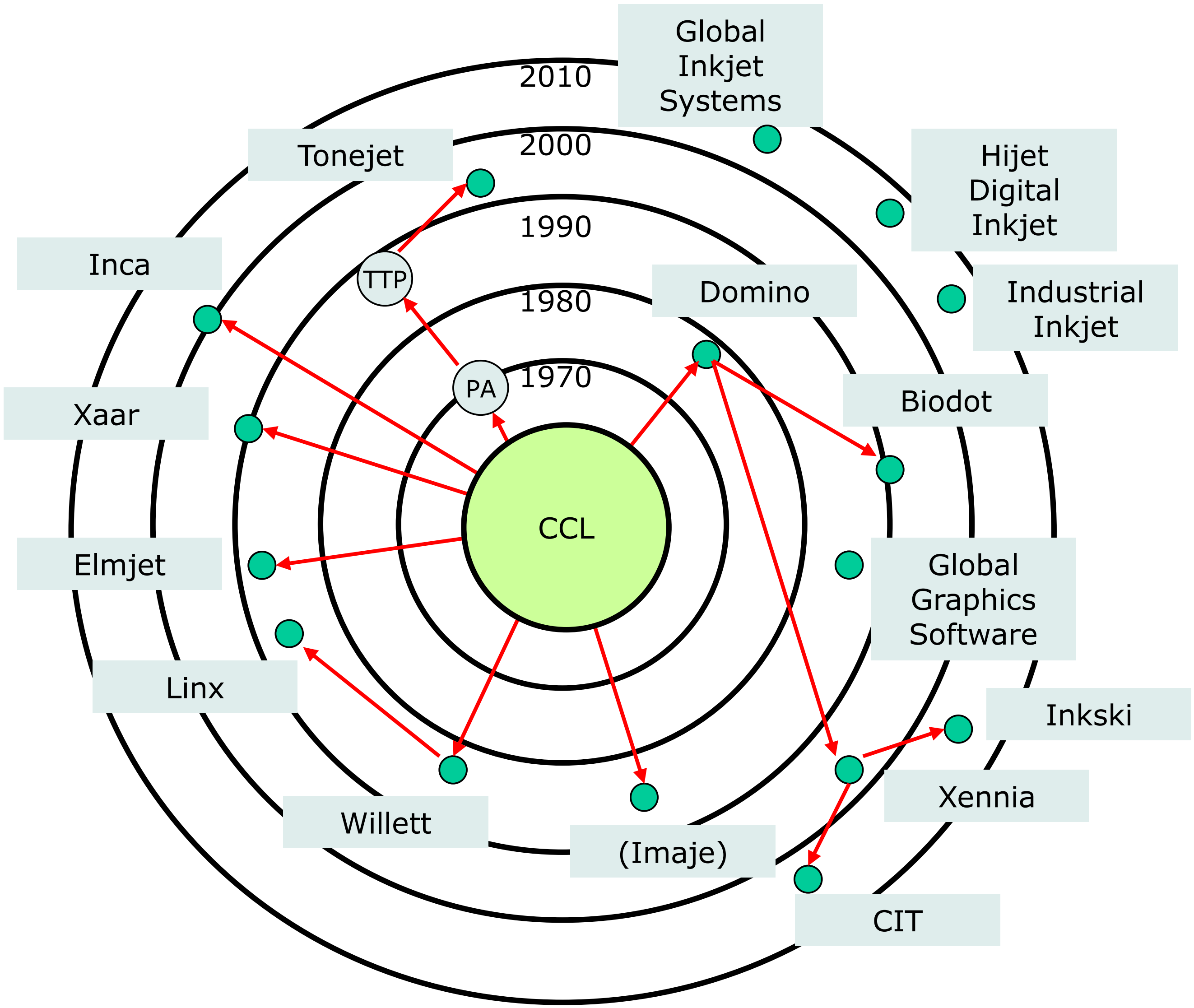
A **wide range of materials** can be deposited.

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




Maturity of technology
Marking & coding
Consumer and SOHO printing
Commercial printing
Manufacturing/Direct writing
1980
1990
2000
2010
2020
Date

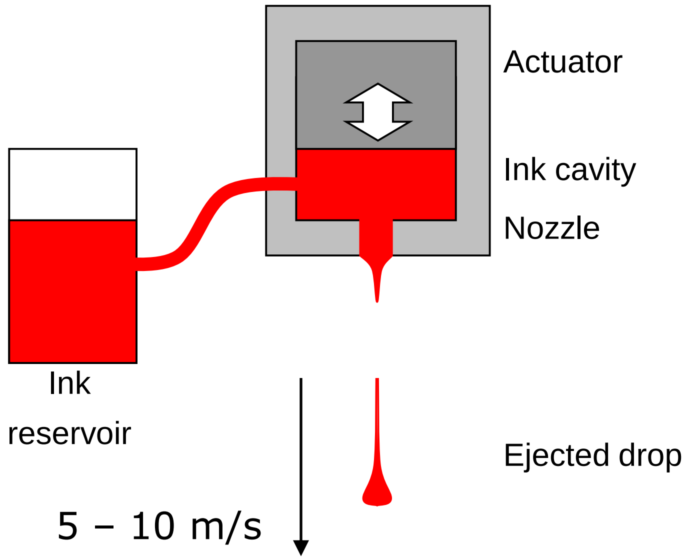
The Cambridge cluster

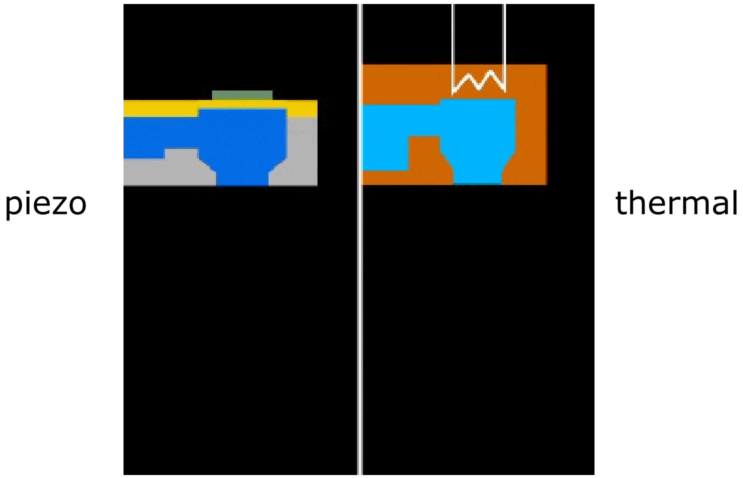


[extended from Garnsey et al. 2009]

Drop-on-demand printing: principles

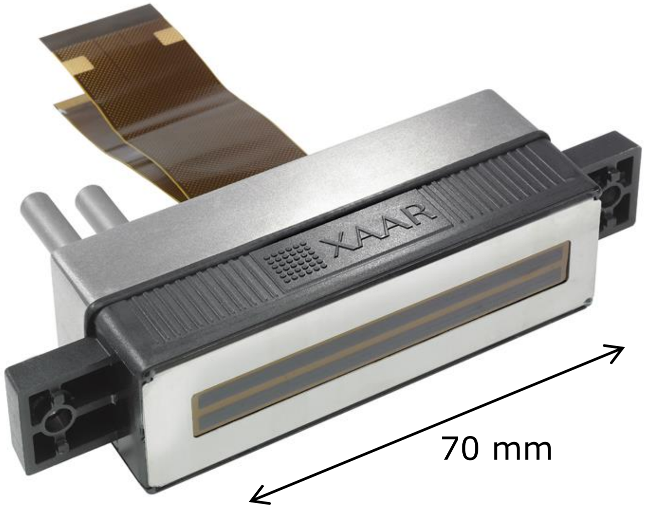
- Each drop (typically 20 – 50 μm diameter) is produced in response to an electrical signal to an actuator in the nozzle chamber
- The printhead contains a large number (hundreds) of separately addressable nozzles
- There are two common types of actuator: thermal and piezo-electric





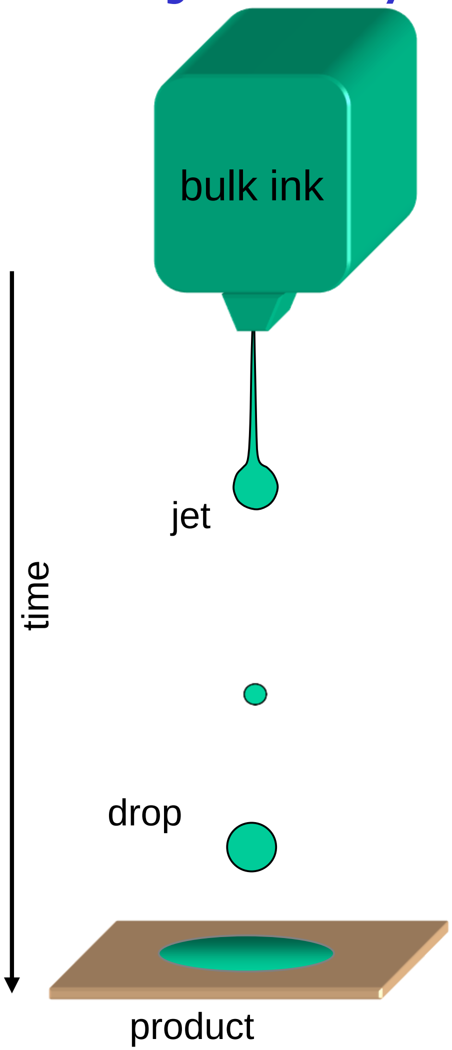
Drop-on-demand: industrial piezoelectric printhead

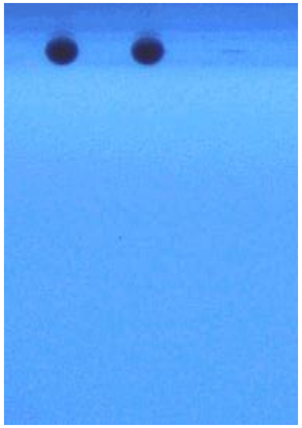
- Example of a modern drop-on-demand industrial printhead:
- 1000 nozzles over 70 mm length i.e. 70 μm spacing
- ~10^4 drops per second emitted from each nozzle
- variable drop volume 6-42 pL (= 22-43 μm diameter)

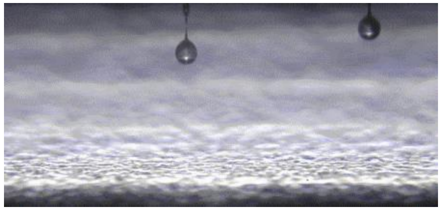


[Image: Xaar]

The journey from nozzle to substrate







dominant physical effects

acoustics

viscosity, inertia

capillarity

electrostatics

aerodynamics

inertia, viscosity

capillarity

dominant chemical effects

solvent/solute / particle interactions

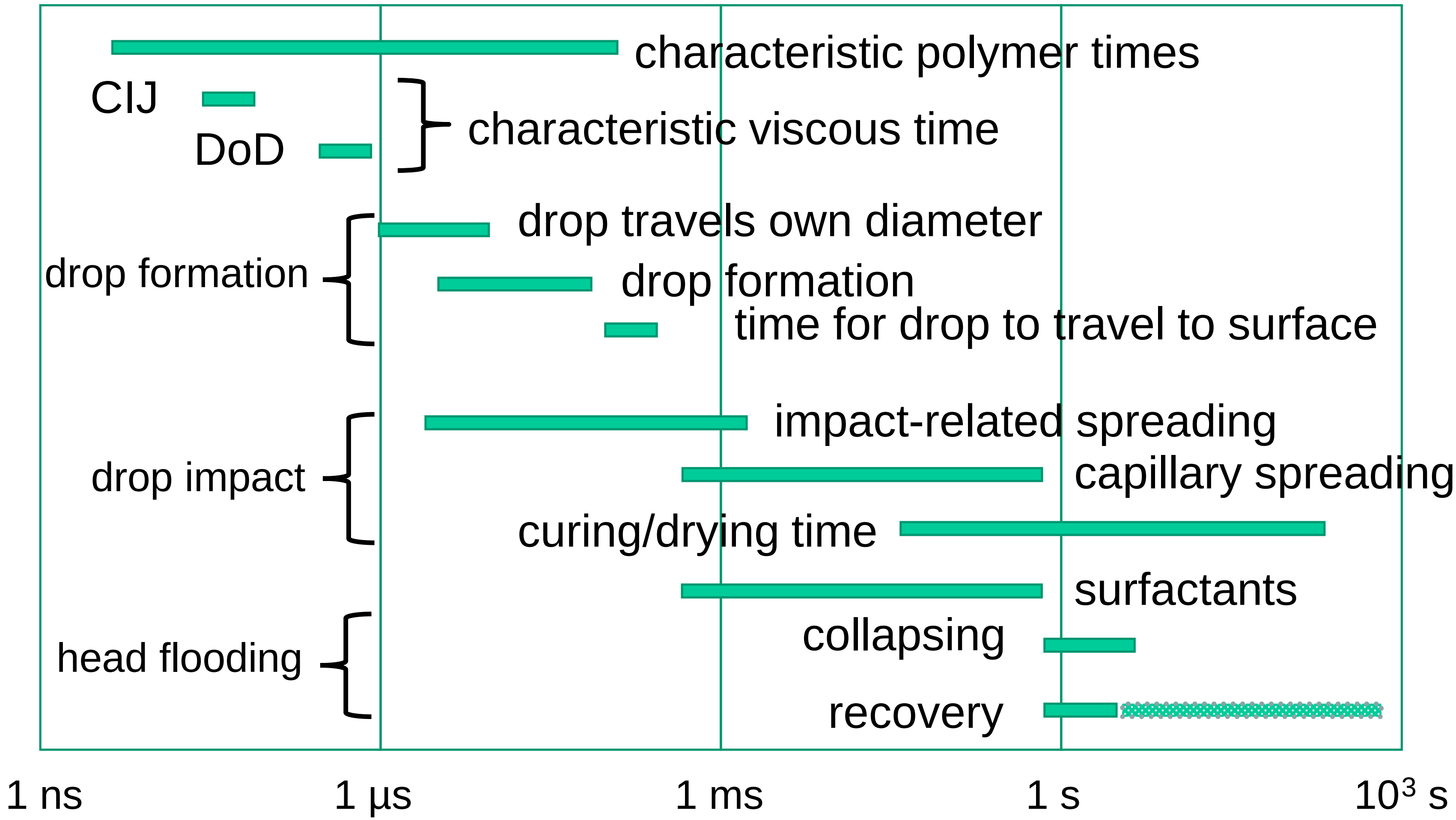
nozzle wetting

solvent/solute / particle interactions

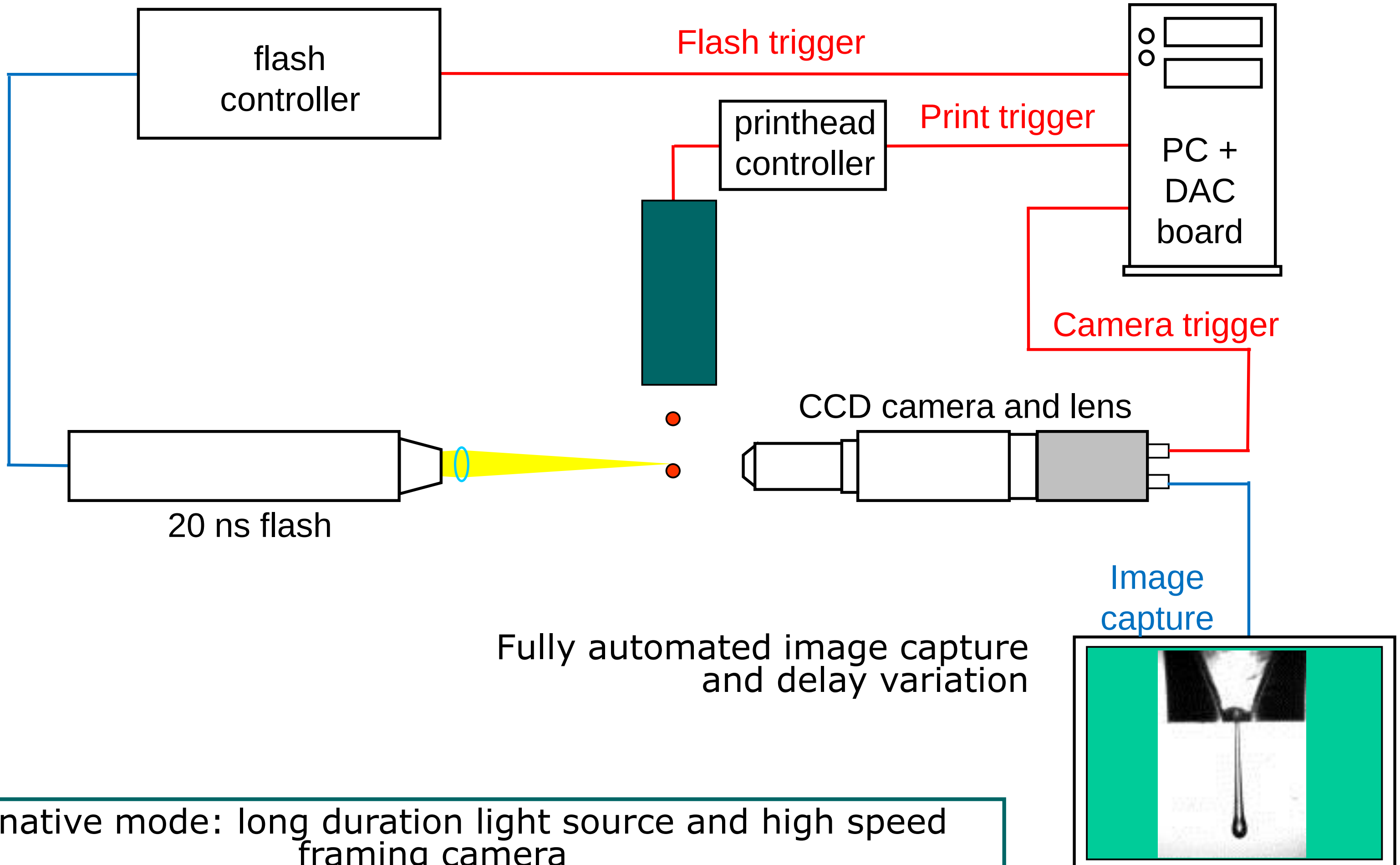
solvent/solute/ particle/surface interactions

drying/curing

Timescales in inkjet printing

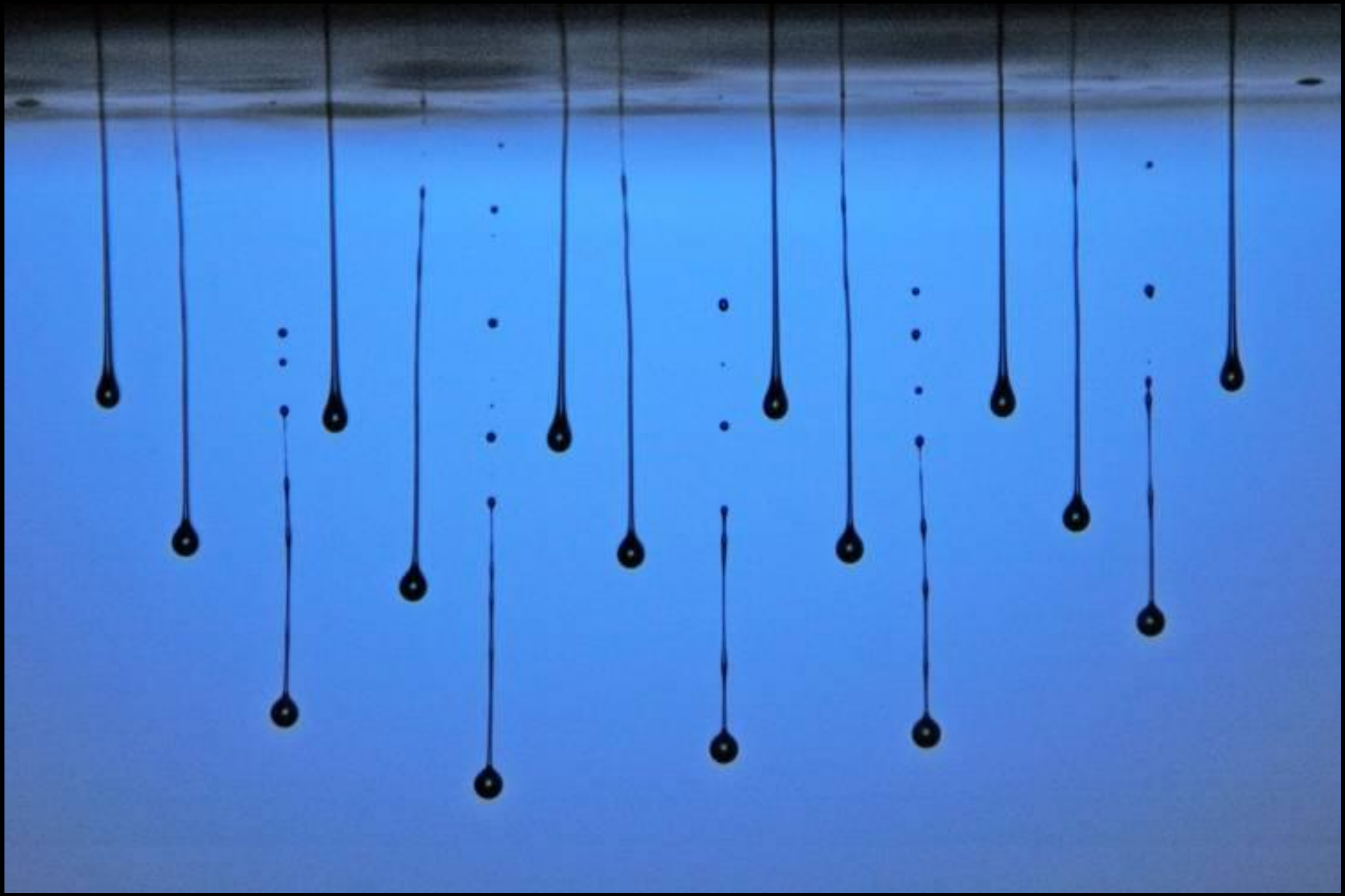


Jet imaging



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

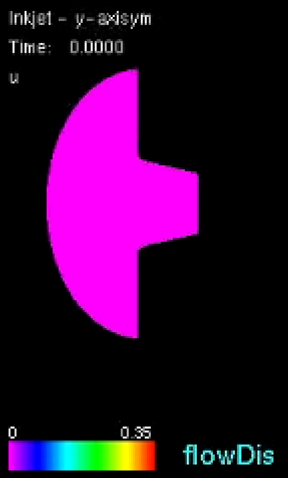
Single-flash image: 20 ns duration



400 µm

Pseudo-sequence of images

Modelling of fluid flow in jet formation



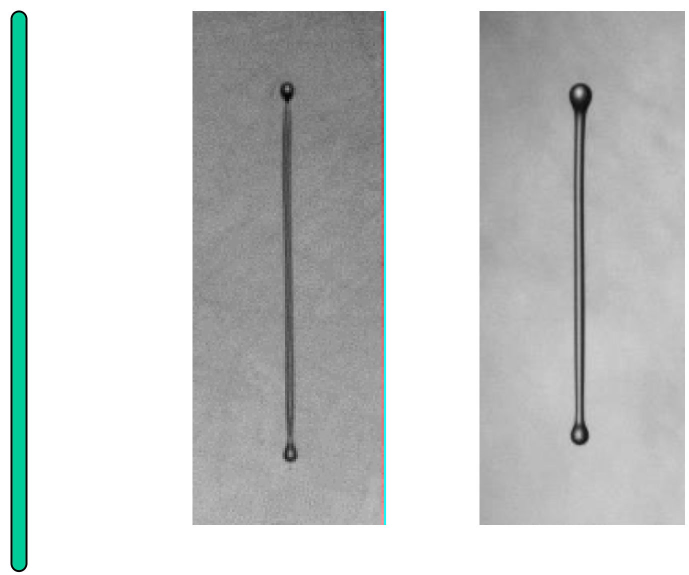
Lagrangian FE model for viscoelastic flows (multiple modes) with inertia & free surfaces

Mesh adaptivity to handle thin filaments & droplet break-off

(Harlen, Yarlanki and Morrison, University of Leeds)

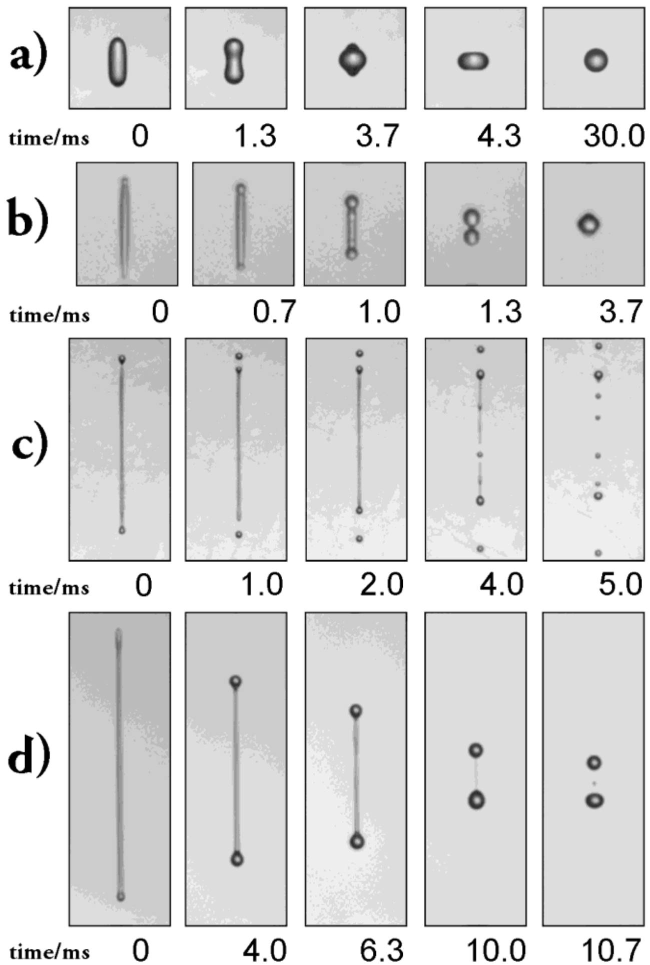
Breakup of liquid filaments

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

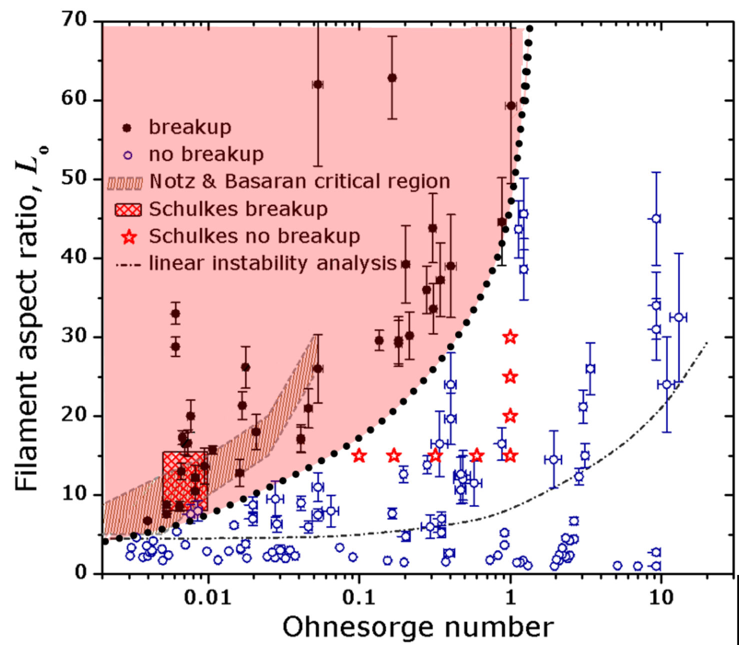


[Castrejon-Pita et al., Phys Rev Lett. **108** (2012) 074506]

Breakup of liquid filaments

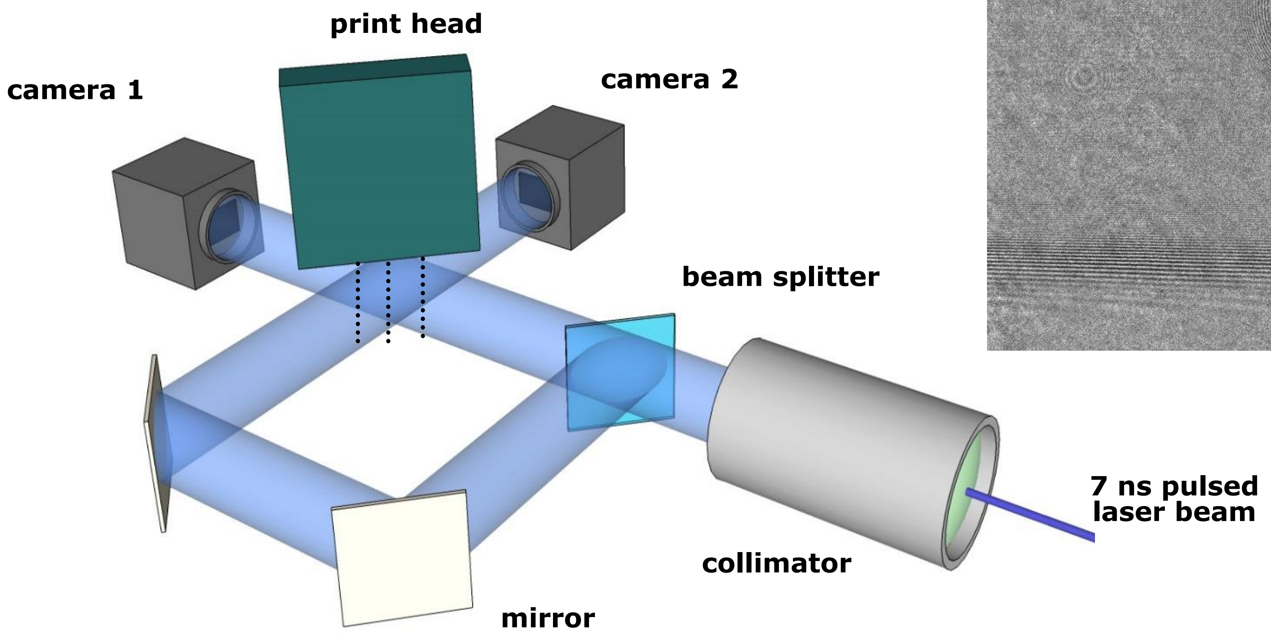


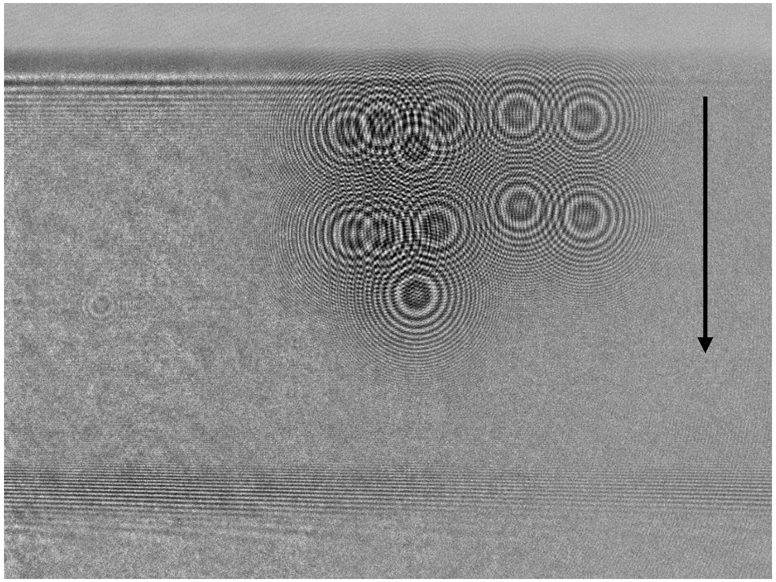
Breakup is controlled by the initial dimensions of the filament and the liquid properties: density, viscosity, and surface tension



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

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

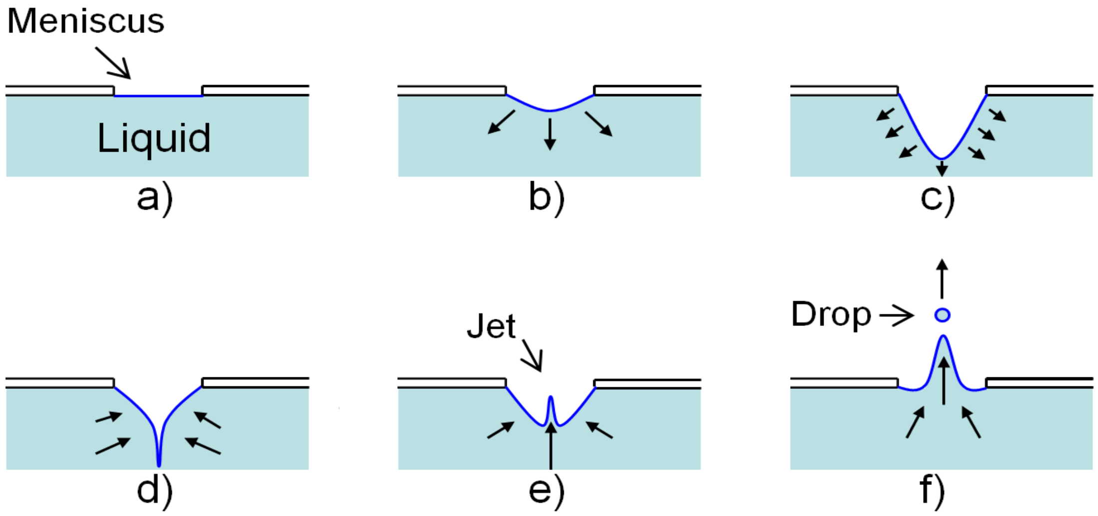


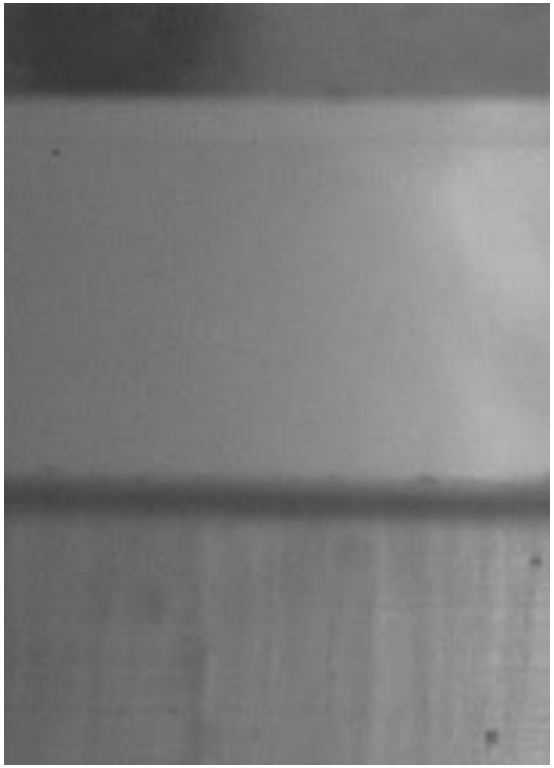


Typical accuracy in measurement of position (x, y, z) and drop radius ±0.3 μm

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

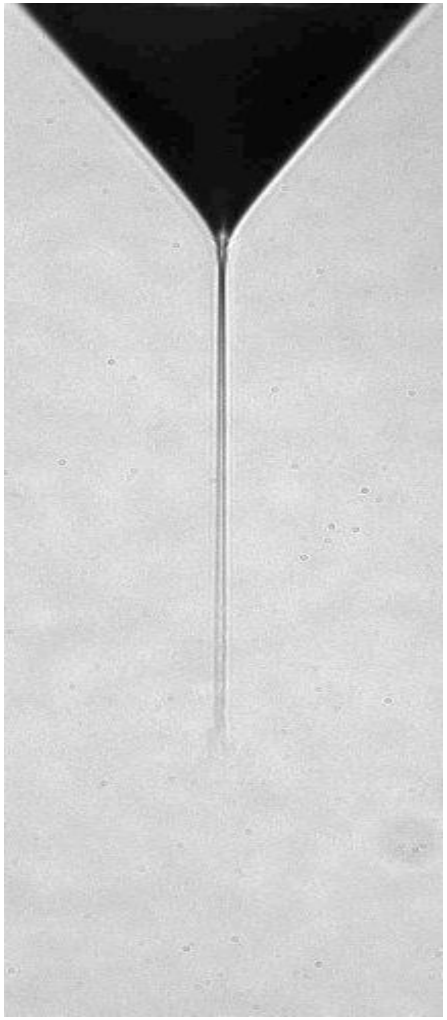
CADET – a new method for generating small drops



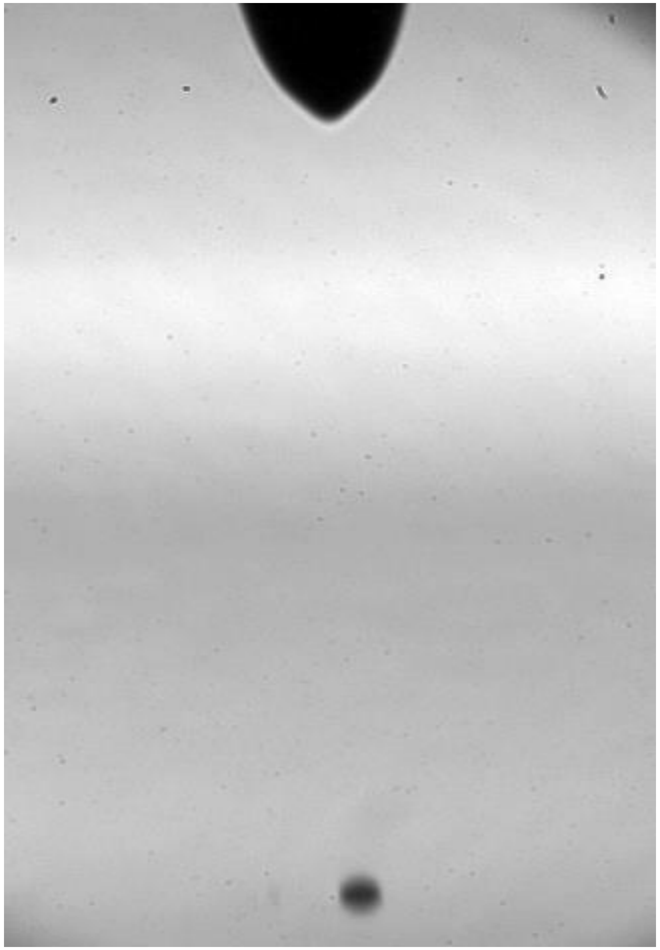


[Castrejon-Pita et al., Rev Sci Inst, 83 (2012) 115105]

Electrohydrodynamic high-resolution deposition

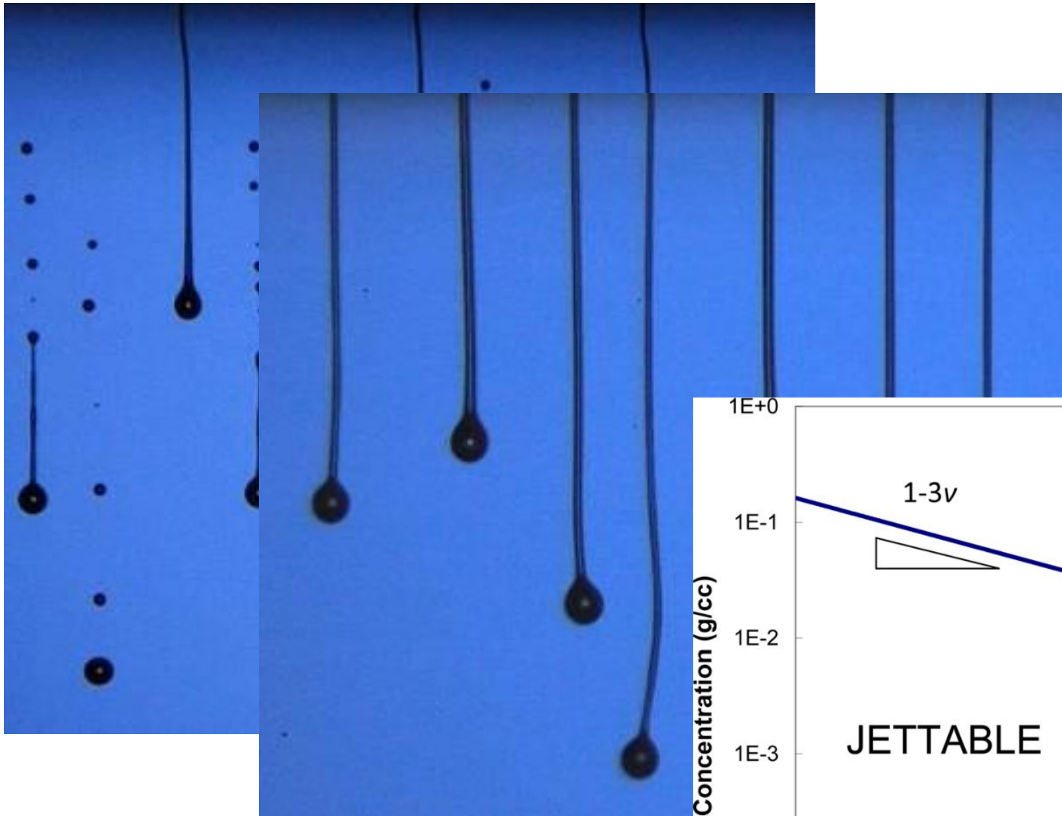


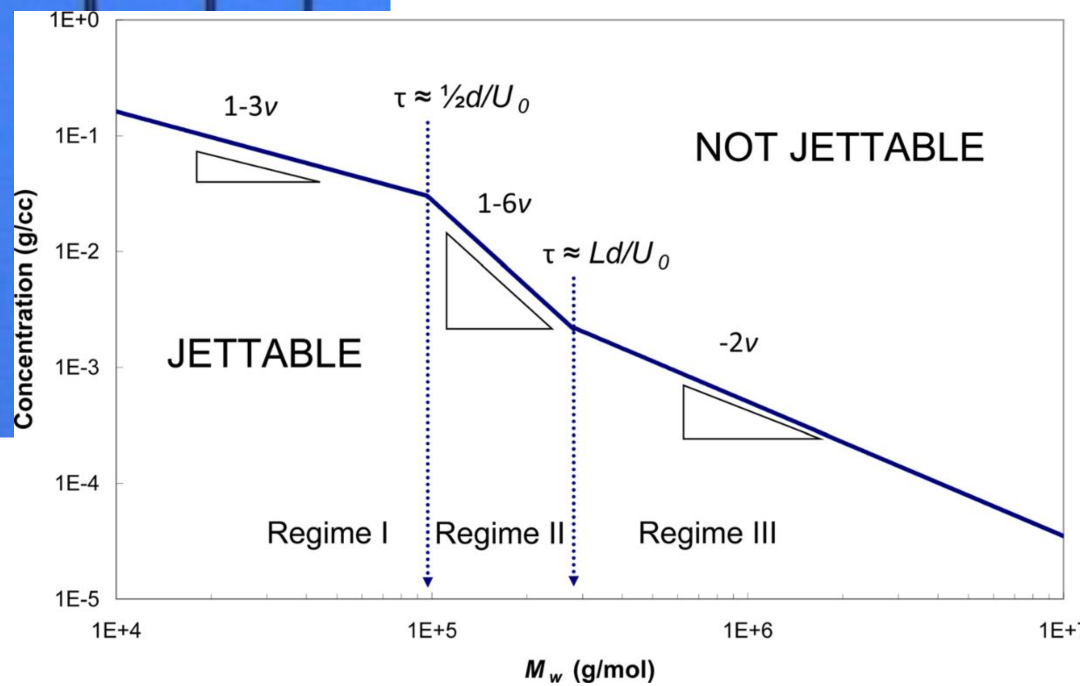
continuous
(electro-spinning)



intermittent
(electro-printing)

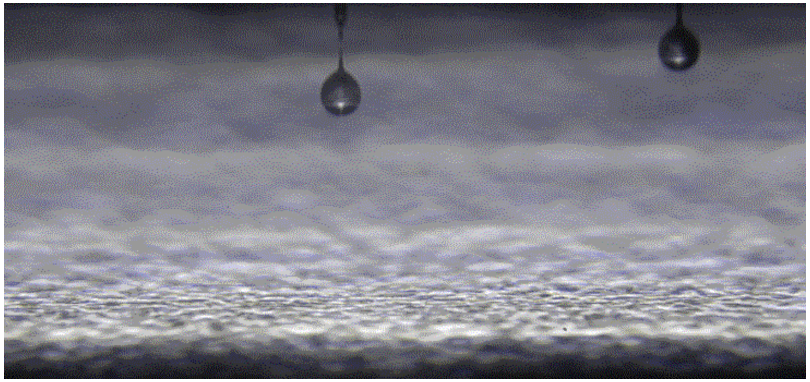
Elastic effects due to polymers in ink





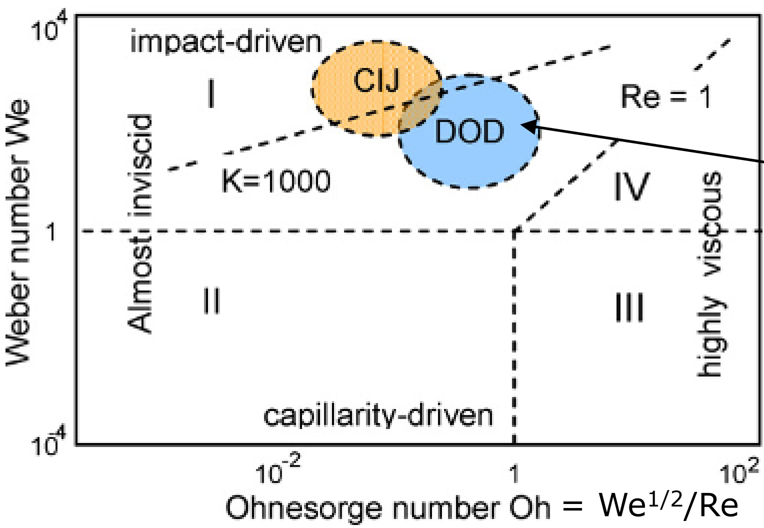
[Hoath et al., J. Rheology, **56** (2012) 1109]

Drop impact



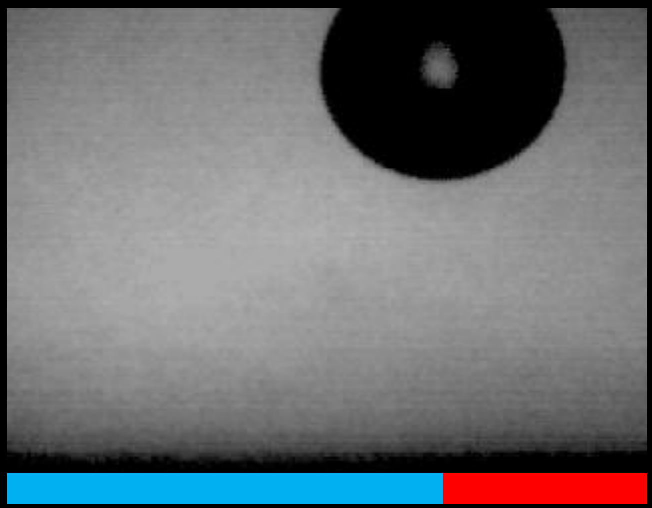
- What happens when a liquid drop hits a surface depends on the relative effects of inertia, viscous and surface tension forces – which can be described by the Reynolds and Weber numbers

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



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

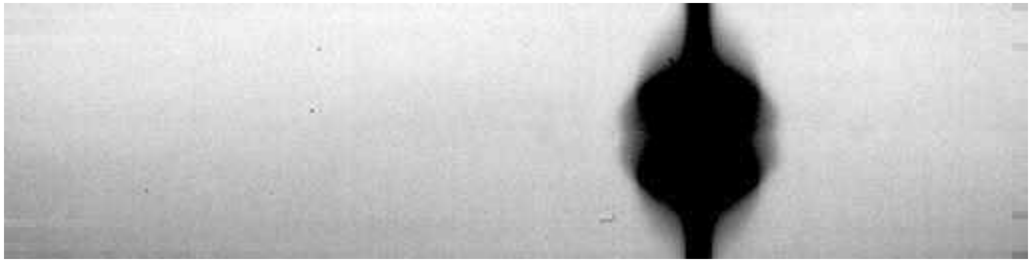


Water drop, 2 mm diameter, 1 m/s
Numerical model based on level set method:
linear viscous fluid with surface tension and gravity
Simulation: Kensuke Yokoi
Experiment: Damien Vadillo, CU Dept of Chemical Engineering

Effect of print frequency/spacing on drop merging


Print frequency: 398 Hz

Effect of print frequency/spacing on drop merging



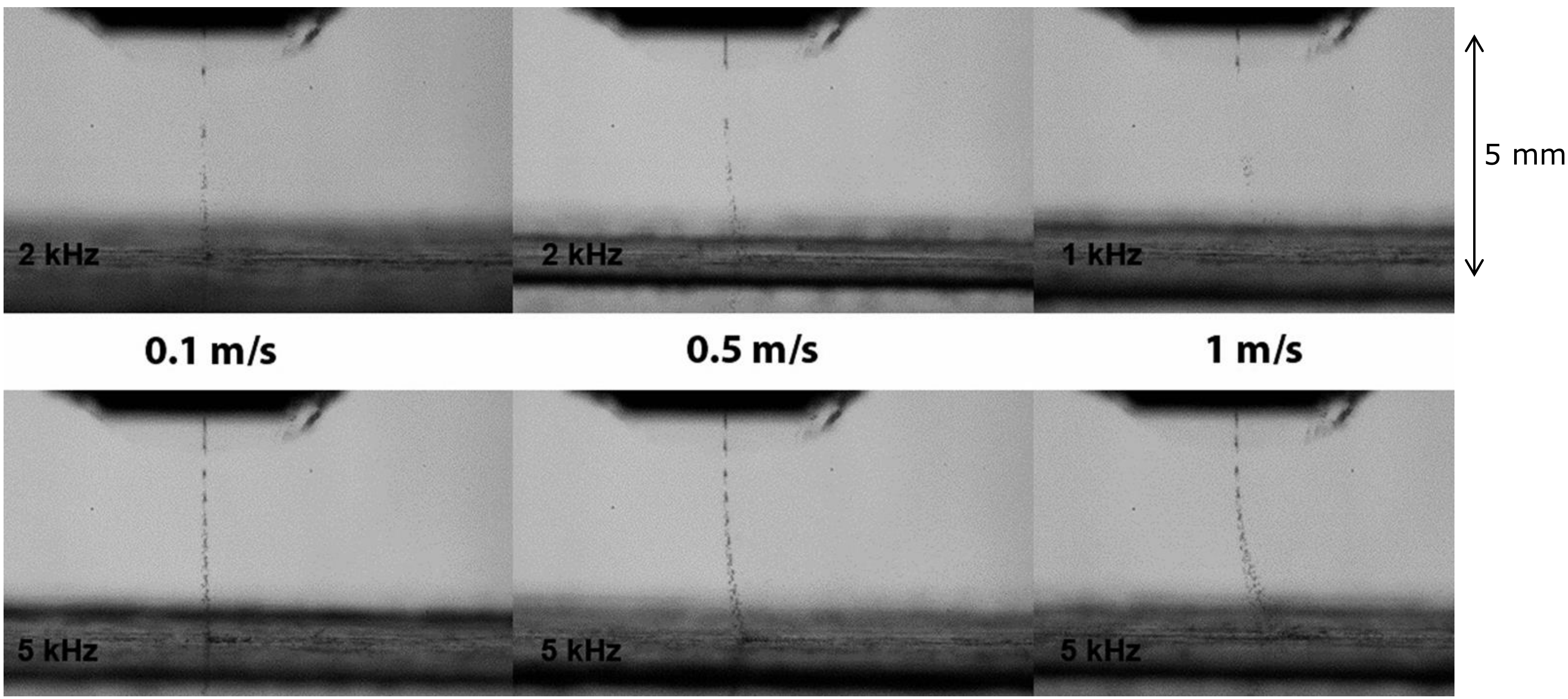
Print frequency: 429 Hz

Aerodynamic effects in printing on a moving substrate

Individual frames from high speed framing camera (41,000 fps, 20 μs exposure time)

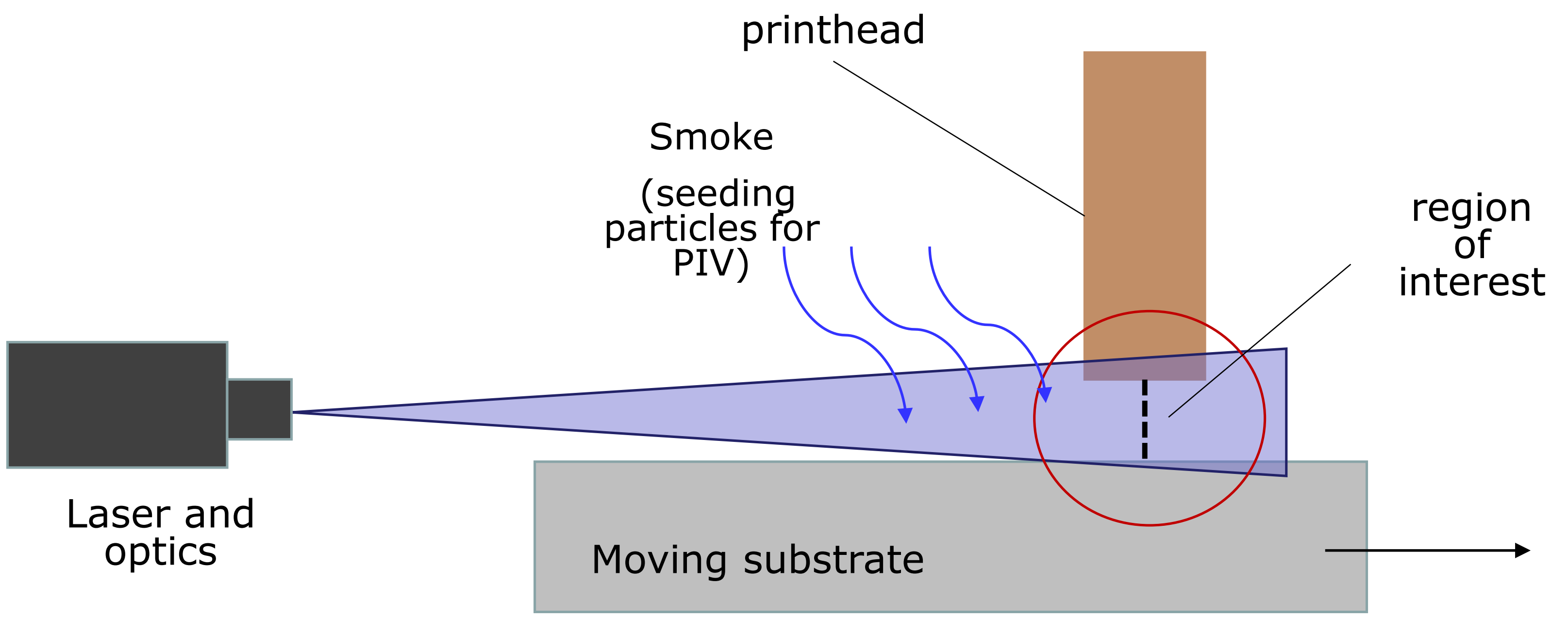
Side view of 20 nozzles

printhead



substrate motion

Aerodynamic effects in printing on a moving substrate



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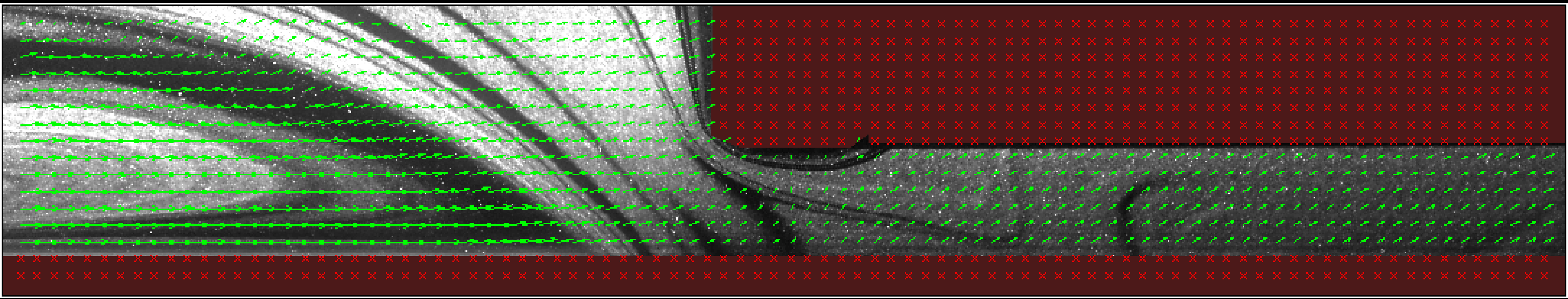


Applications of inkjet in manufacturing

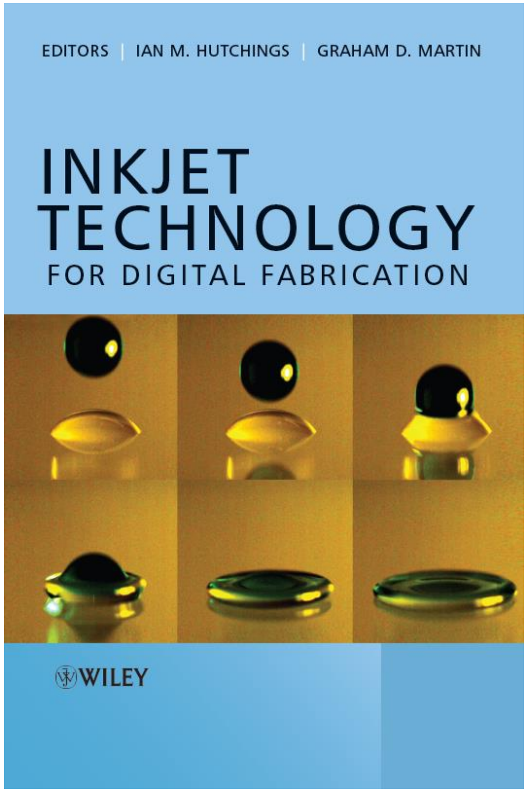
NOW

- 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

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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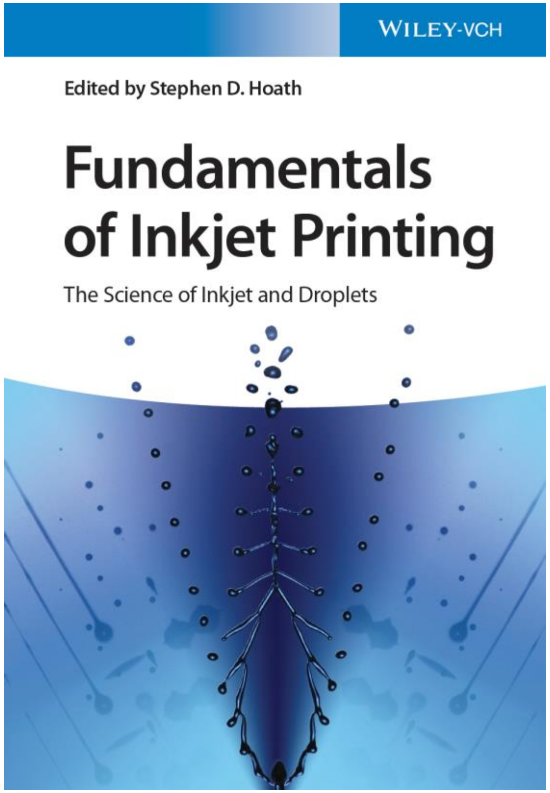
WILEY-VCH
Edited by Stephen D. Hoath
Fundamentals
of Inkjet Printing
The Science of Inkjet and Droplets

Inkjet Interest Group

6-monthly evening meetings - presentations plus dinner

Next meeting: 28 July 2015

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/