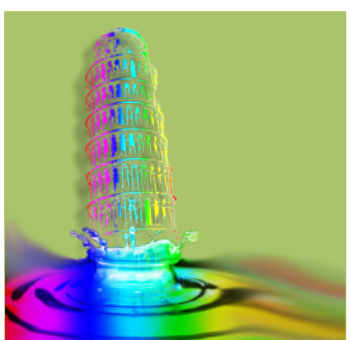
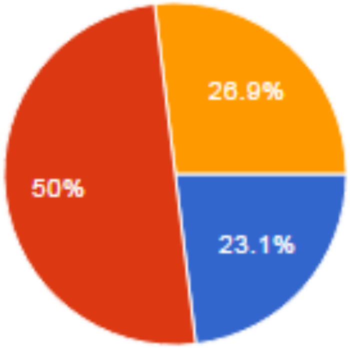


Inkjet Printing

carmelo.demaria@centropiaggio.unipi.it

Question 1 – 14/10/2015

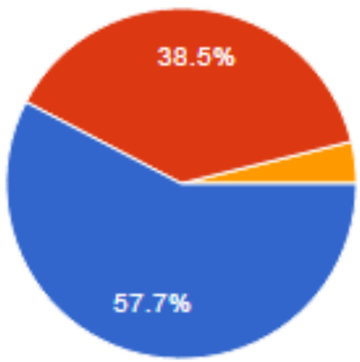
The weight of 7 meters PLA filament (diameter 3 mm) is



less than 100 g	**6**	23.1%
between 100g and 150 g	**13**	50%
more than 150 g	**7**	26.9%

Question 2 – 14/10/2015

How many meters of PLA (diameter 3 mm) I need To print a full density 5cm-side cube?



less than 10	**15**	57.7%
between 10 and 20	**10**	38.5%
more than 20	**1**	3.8%

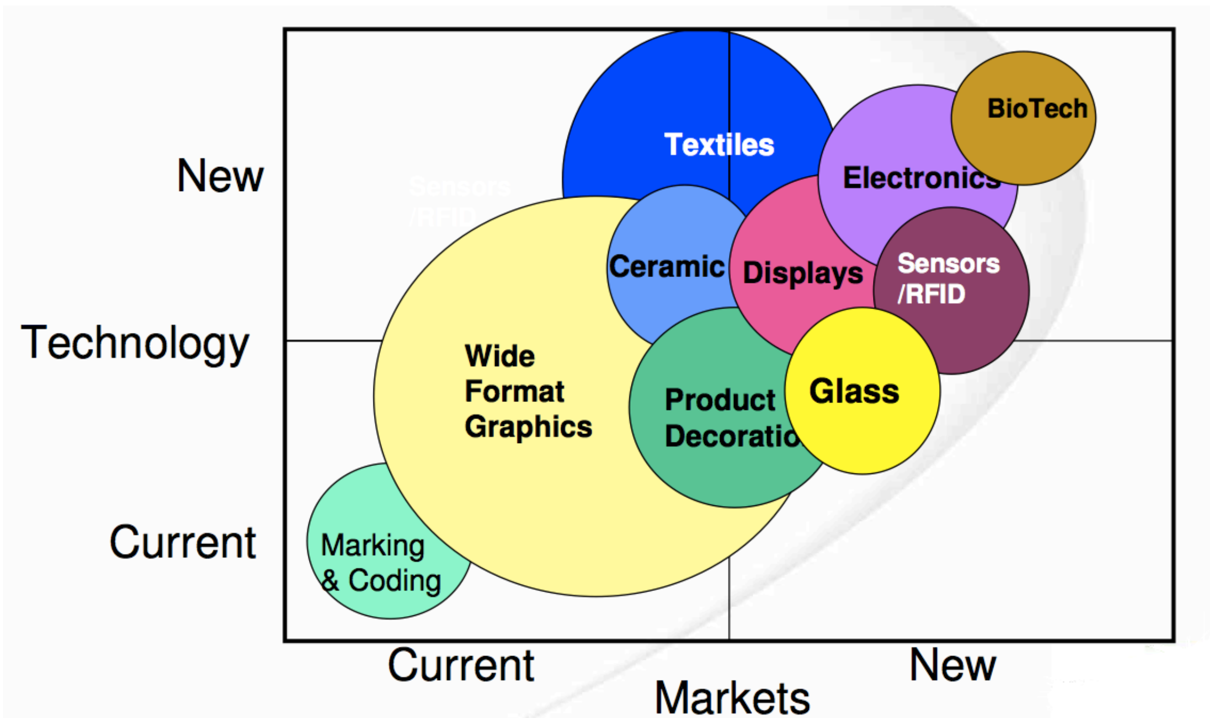
+ # Question time

http://goo.gl/forms/ciDL8ZWF0I

Ink-jet technology

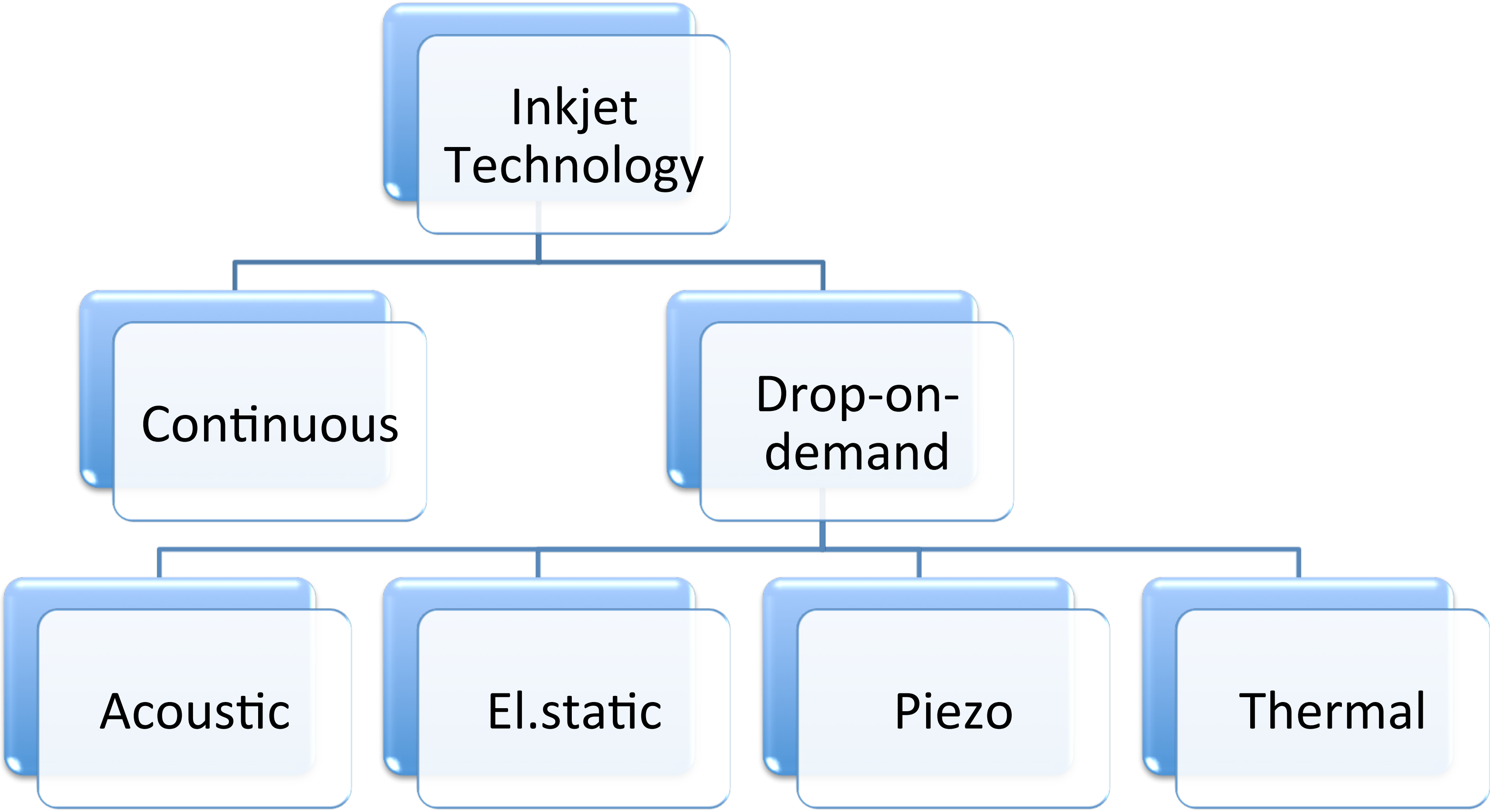
- The ink-jet technology is a contact free dot matrix printing procedure. Ink is issued from a small aperture directly onto a specific position on a medium

Inkjet technology

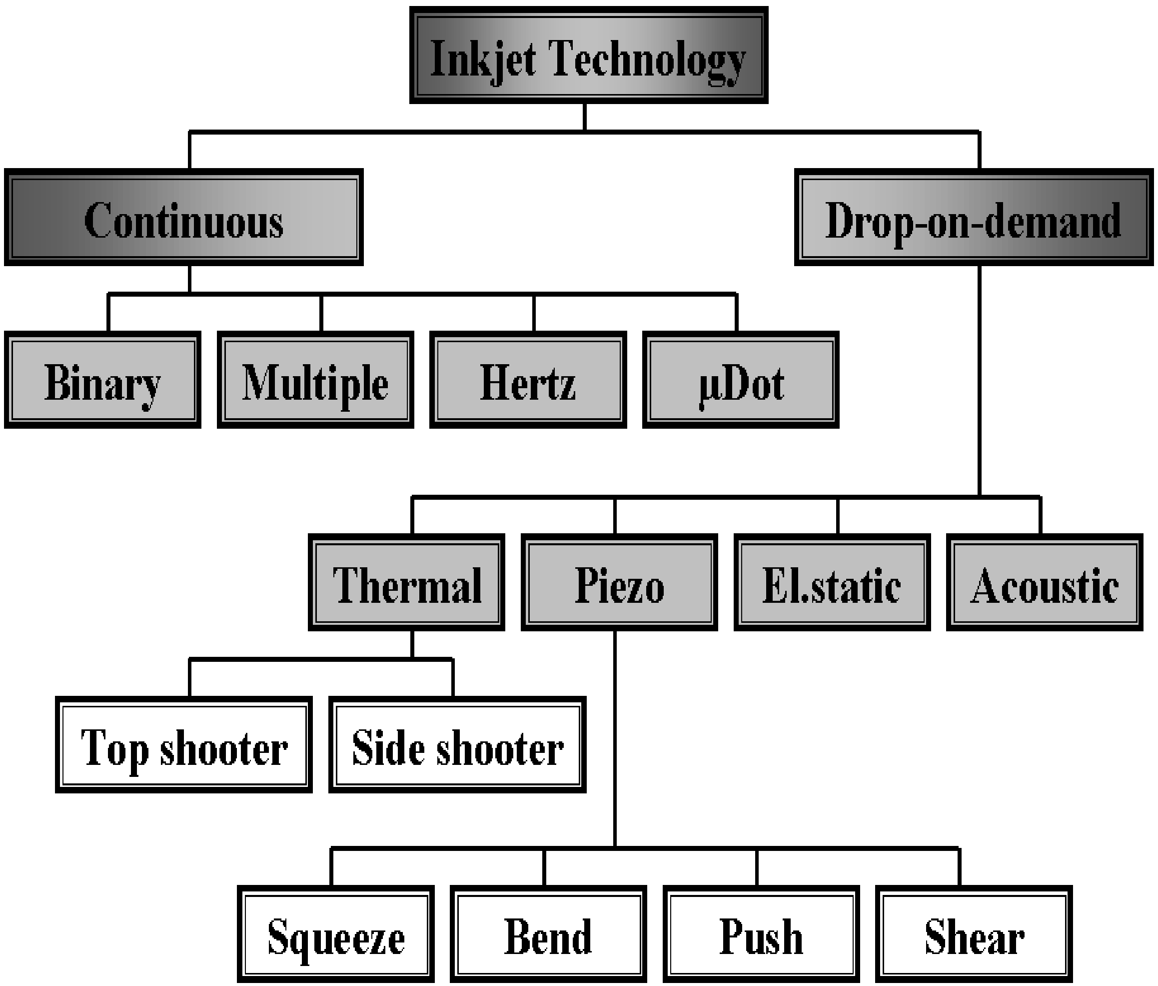


X. Wang. Nanotech Conference & Expo 2009, Houston, TX, (2009)

Inkjet technologies

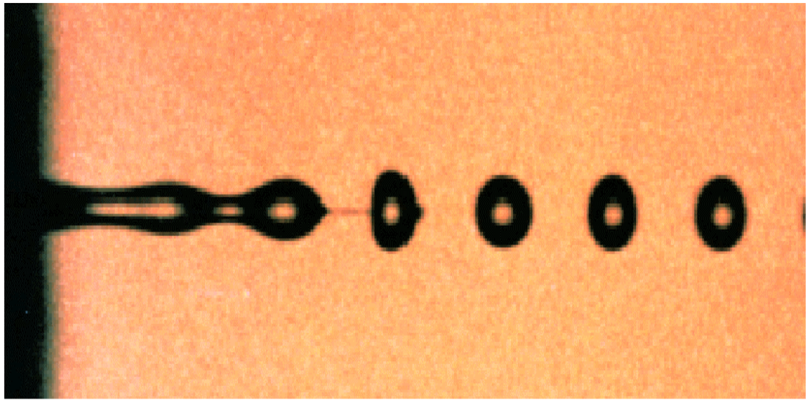


Mechanisms of drop formation



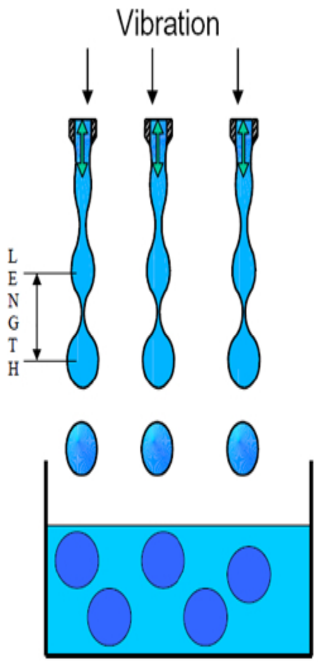
Continuous Ink-Jet (CIJ)

- Plateau-Rayleigh instability
  - A falling stream of fluid breaks up into smaller drops (the liquid is unstable)
  - When a jet is thin enough, the effect of gravity is negligible compared to surface energy
  - The jet changes its shape to reduce the total surface energy
  - Liquid flow sets the time.



Continuous Ink-Jet (CIJ)

- Minimum of surface energy
- Varicose perturbation (unstable system)
- No constant radius of curvature
- Time and length scale
- Drop radius



Continuous Ink-Jet (CIJ)

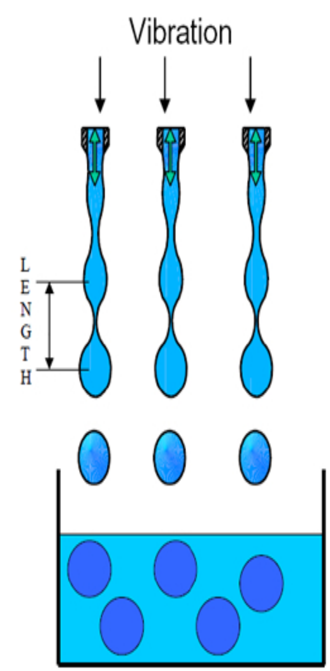
- Mathematical modelling

$$L_{crit} = f\left(\rho, R, U_{jet}, \gamma\right)$$

$$\frac{L_{crit}}{R} = 2.74\left[U\left(\frac{\rho R}{\gamma}\right)^{\frac{1}{2}}\right]$$

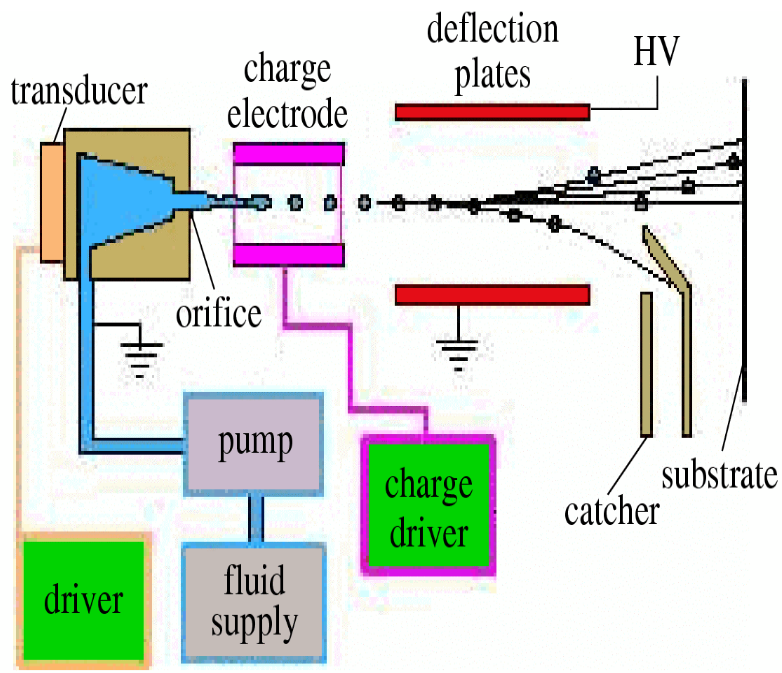
$$T_{crit} = 2.74\left(\frac{\rho R^3}{\gamma}\right)^{\frac{1}{2}}$$

$$\frac{R'}{R_0} \approx \left(\frac{\pi}{0.697}\right)^{\frac{1}{2}} \approx 2.1$$

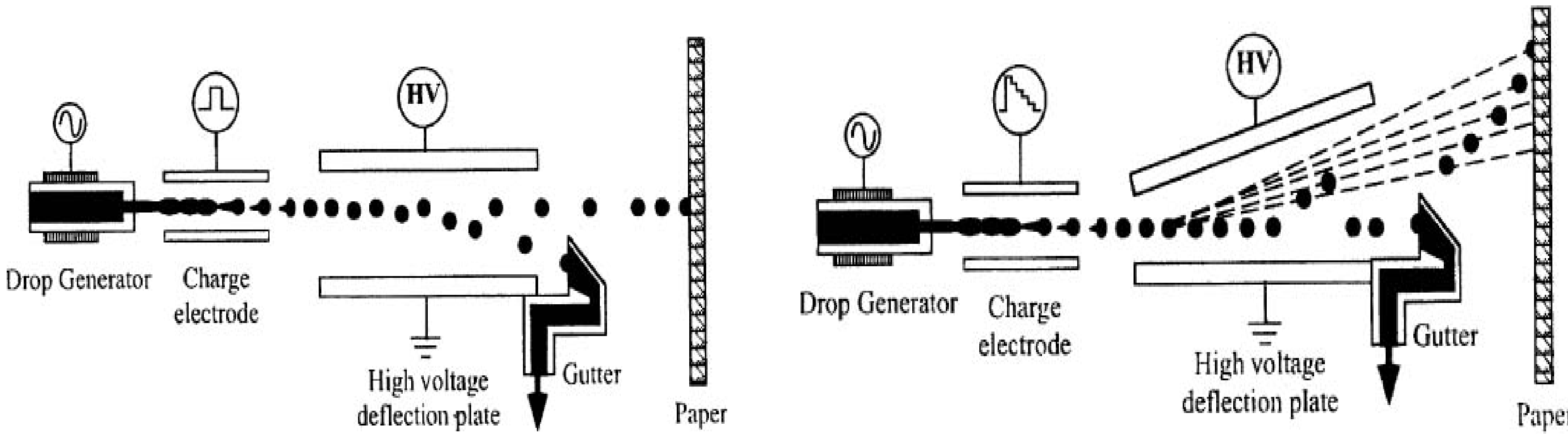


Continuous Ink-Jet (CIJ)

- Dedicated charging of droplets
- Recirculation by deflection in transversal electrical field



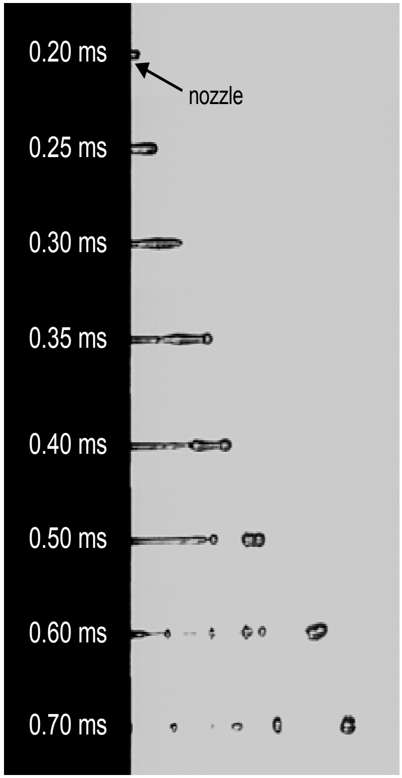
+ Continuous Ink-Jet (CIJ)



- Binary deflection
  - Uncharged droples dispended on substrate
  - Charged droplets recirculate
- Multiple deflection
  - Uncharged droplets recirculated by gutter
  - Charged droplets deflected according to q/m ration
  - 2-dimensional writing of small areas with single nozzle

Continuous Ink-Jet (CIJ)

- Droplet delivery
  - Emission of cylindrical plug from orifice
  - Stimulated break-off (induced varicosity)
  - Charging by passing electric field (ring or tunnel)
  - Orifice diameter 50-80 um
  - Droplet size ≅ 120 um (volume 4fl – 1pl)
  - Droplet frequencies in order of 100 kHz
  - Frequently satellite droples formed



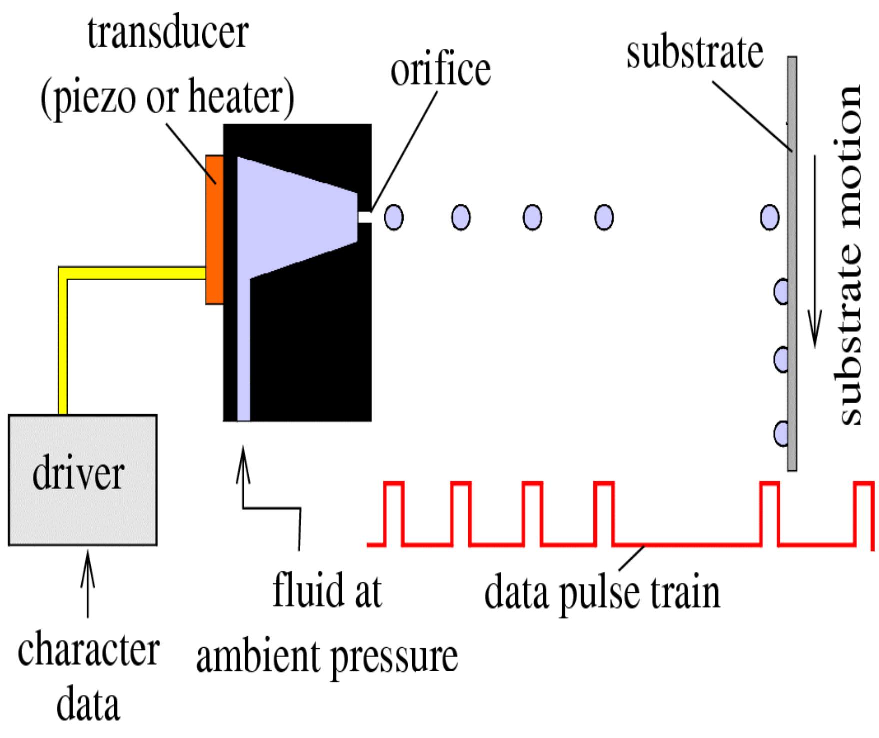
Continuous Ink-Jet (CIJ)

- Drawbacks
  - Complex recirculation
  - Deflection according to charge-to-mass ratio (limited accuracy)
  - Restriction to conducting ink formulas
  - Low quality
- Application
- Industrial small-character printing (SCP)
  - Zanasi
  - http://www.youtube.com/watch?v=BZfjcNDj4uY

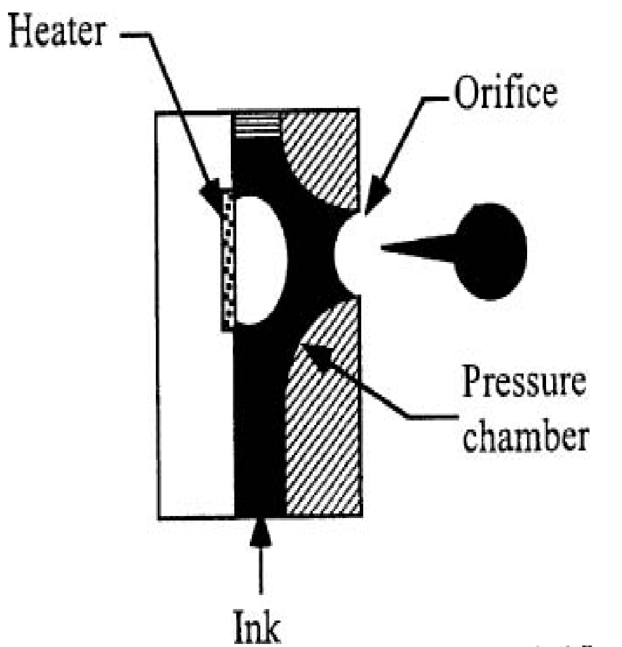
DROP ON DEMAND (DOD)

Drop On Demand (DoD)

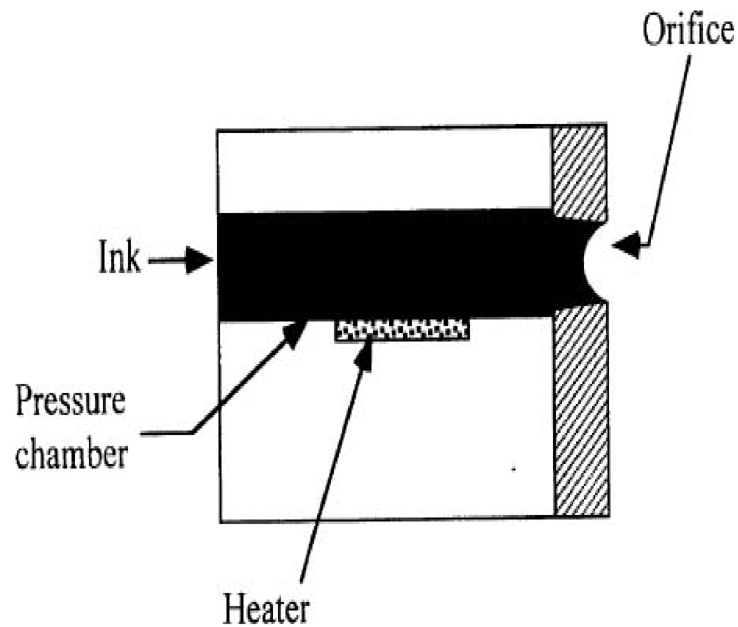
- Mechanism of droplet formation:
  - <u>Thermal</u>
  - <u>Piezo-electric</u>
  - Electrostatic
  - Acoustic



DoD – Thermal Ink-Jet (TIJ)



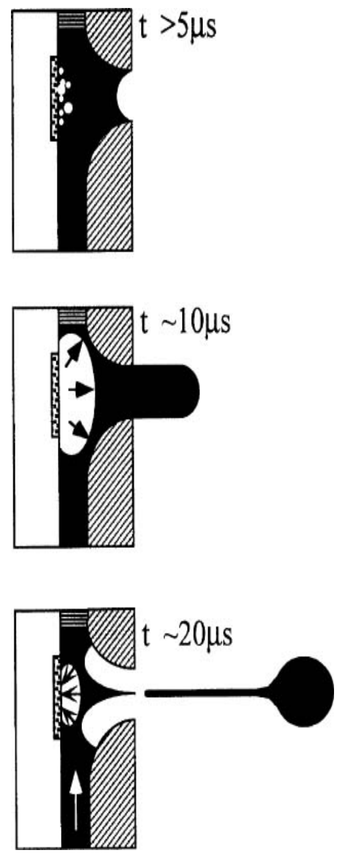
- Roof shooter
  - Heater above orifice (HP, Lexmark, Olivetti)

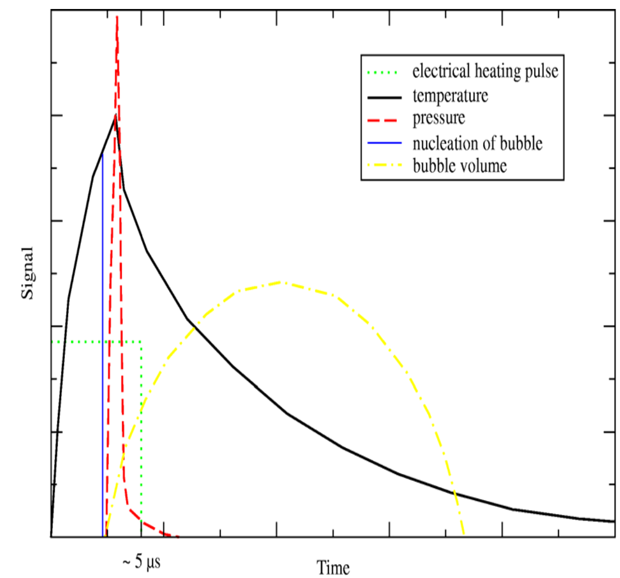


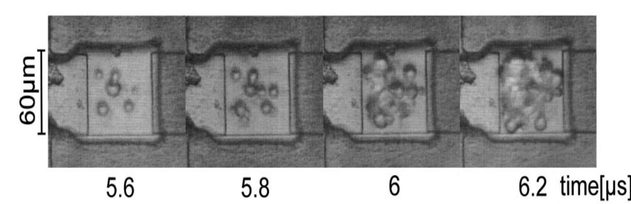
- Side shoother
  - Heater lateral to horifice (Canon and Xerox)

DoD – Thermal Ink-Jet (TIJ)

- Phase of droplet formation
- Heating
  - Overheated ink (over the spinodal limit, around 300°C for water)
  - At 300°C: nucleation of bubble
- Expansion
  - Ejection of ink
  - Parallel to bubble expansion
- Droplet formation
  - Collapsing vapour bubble
  - Retraction of bulk ink
  - Refilling of cavity (80-200 us, speed critical step)

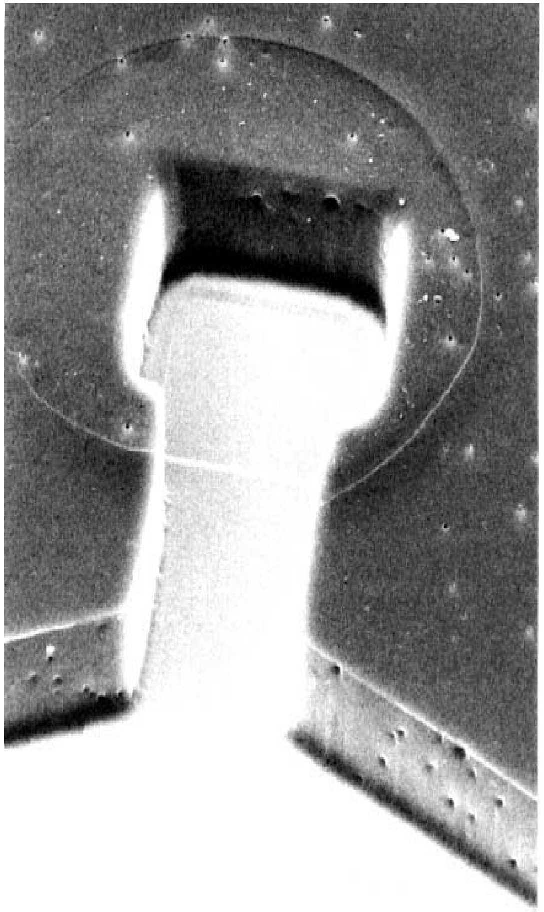






DoD – Thermal Ink-Jet (TIJ)

- Example: nozzle of DJ 850C color printhead
- Roof shooter
- 6000 droplets a 32 pl per second (cycle time 170 us)
- Widht and height of ink channel on um range
- Critical produciton parameters
  - Dimensional stability
  - Precision
  - Uniformity of nozzles
- Drop performance
  - Frequency
  - Volume
  - Speed



DoD – Thermal Ink-Jet (TIJ)

- A case of study

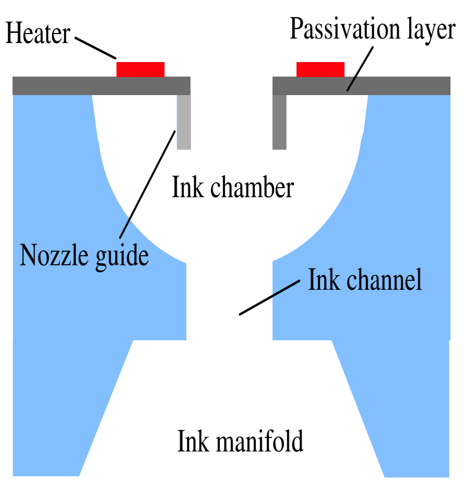
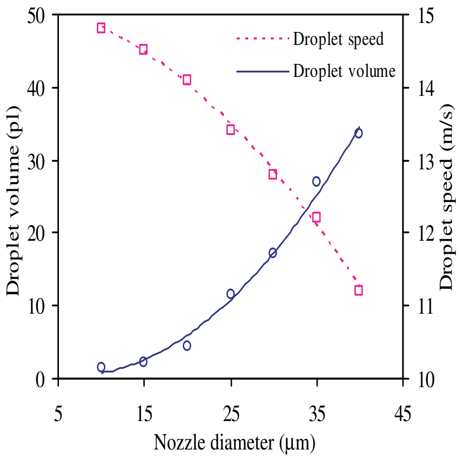
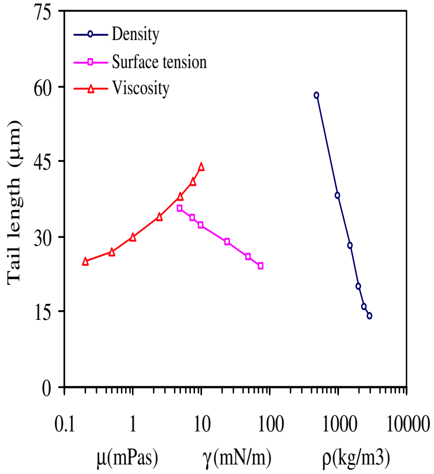
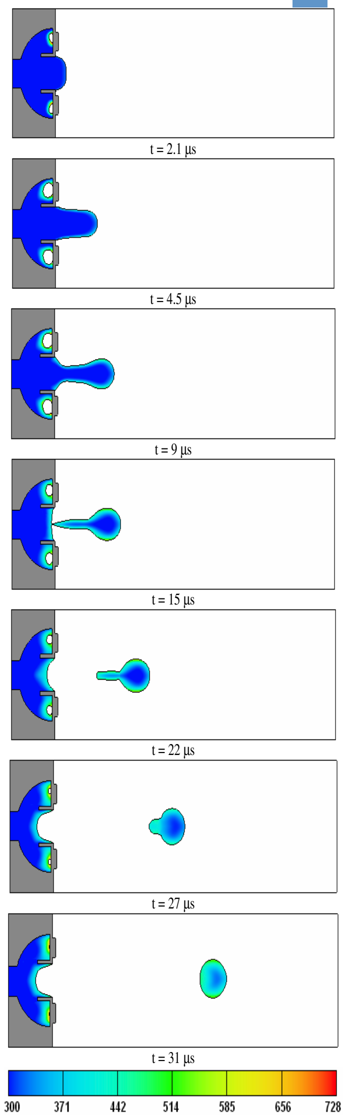


Figure 1. A cross-sectional view of the inkjet print head.



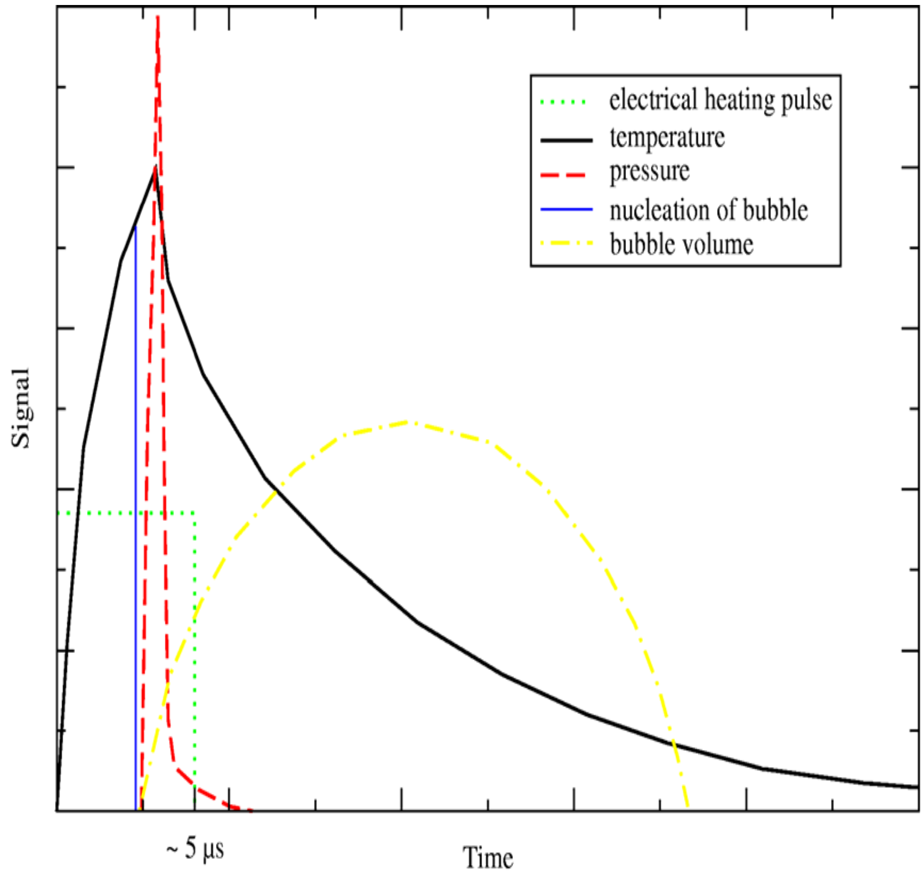




Droplet ejection performance of a monolithic thermal inkjet print head - 2007 J. Micromech. Microeng. 17 1420

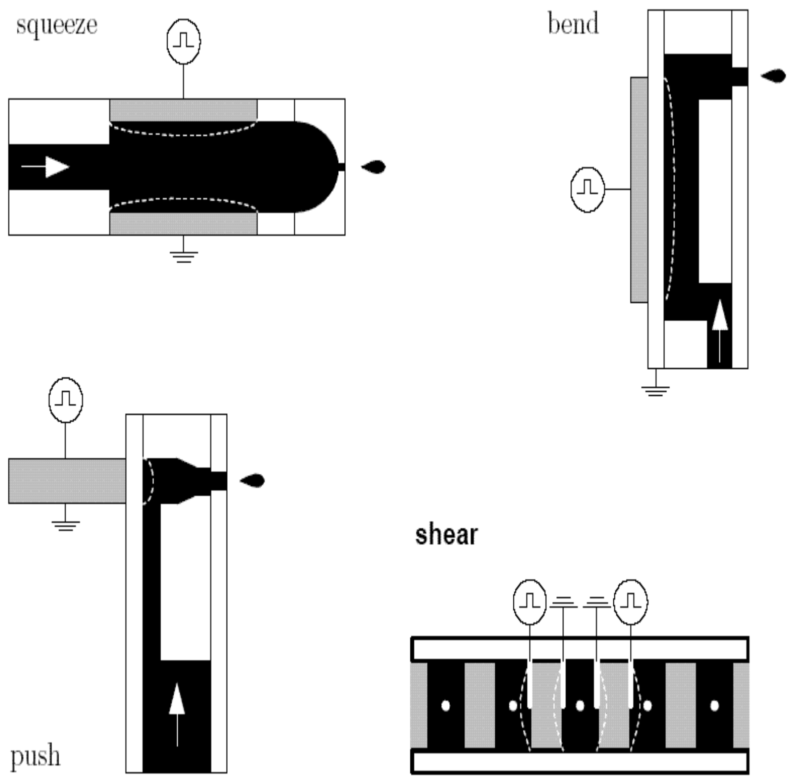
Exercise

- Estimate the penetration depth of the temperature into a drop during thermal inkjet printer.

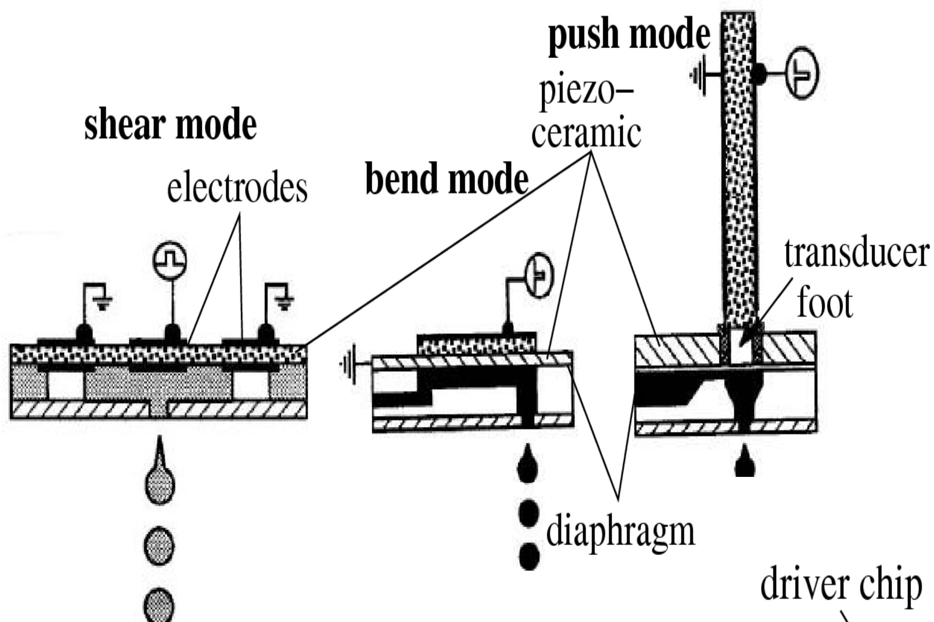


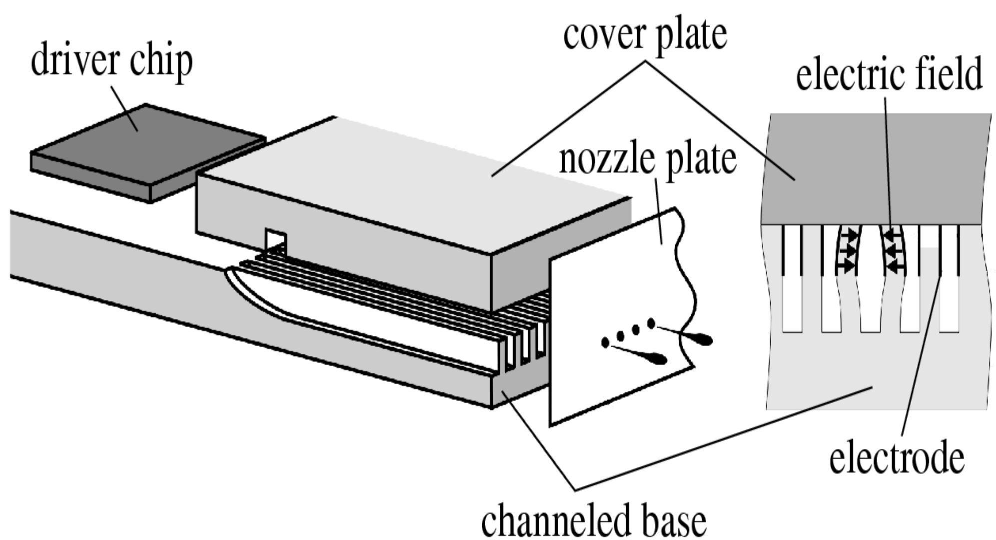
DOP – piezo-electric IJ

- Deformation of piezo-ceramics
- Change in volume
- Pressure wave propagates to nozzle
- Deflection of piezo-ceramics in submicrometric range
- Piezo-element has to be much larger than orifice
- Main problem: miniaturization



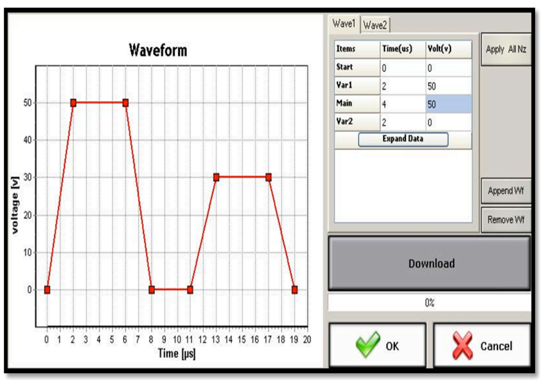
DOP – piezo-electric IJ

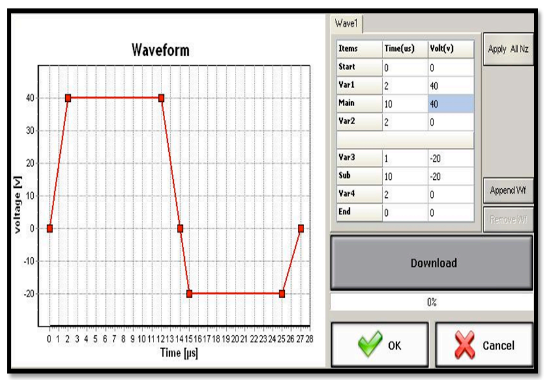




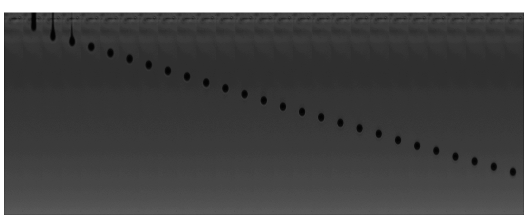
DOP – piezo-electric IJ

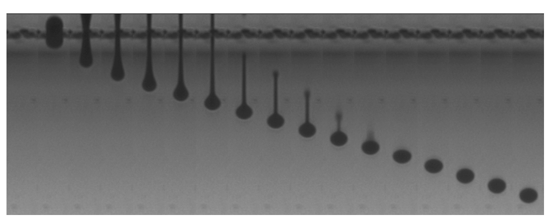
- OmniJet 100 – samsung cartridges
- Signal waveform





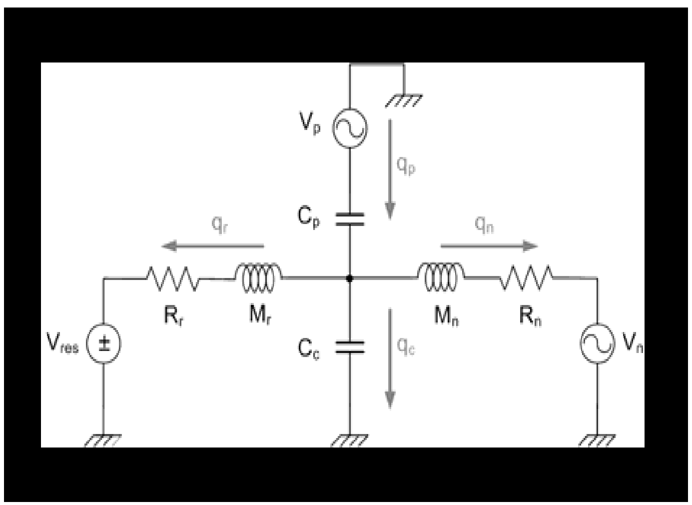
	SPECIFICATION
Number of Nozzles	16 nozzles
Nozzle Spacing	508 um (50 DPI, single row)
Driving voltage	< 100V
Jetting frequency	up to 30 kHz
Droplet volume	1, 5 & 30 pL (3 types)
Operating temp.	< 50 ℃
Reservoir capacity	5 mL
Size (W×L×H)	39 mm × 16 mm × 56 mm

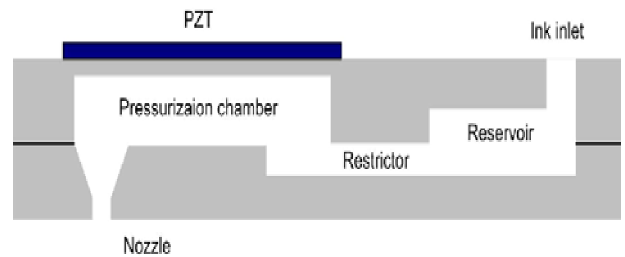




DoD – piezo-electric IJ

- Lumped model
- Electromechanic modelling (Maxwell Approach)



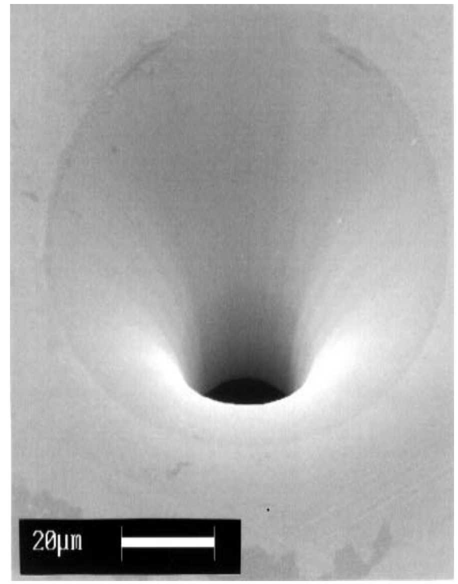


$$\ddot{q}_r = -\frac{1}{M_r}\left\{R_r \dot{q}_r + \frac{1}{C_p + C_c} q_r + \frac{1}{C_p + C_c} q_n - \frac{C_p}{C_p + C_c} V_p + V_{res}\right\} \qquad (1)$$

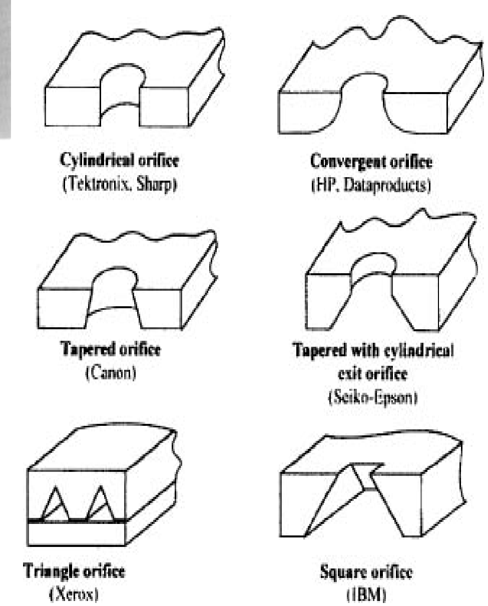
$$\ddot{q}_n = -\frac{1}{M_n}\left\{R_n \dot{q}_n + \frac{1}{C_p + C_c} q_r + \frac{1}{C_p + C_c} q_n - \frac{C_p}{C_p + C_c} V_p + V_m\right\} \qquad (2)$$

Nozzle design

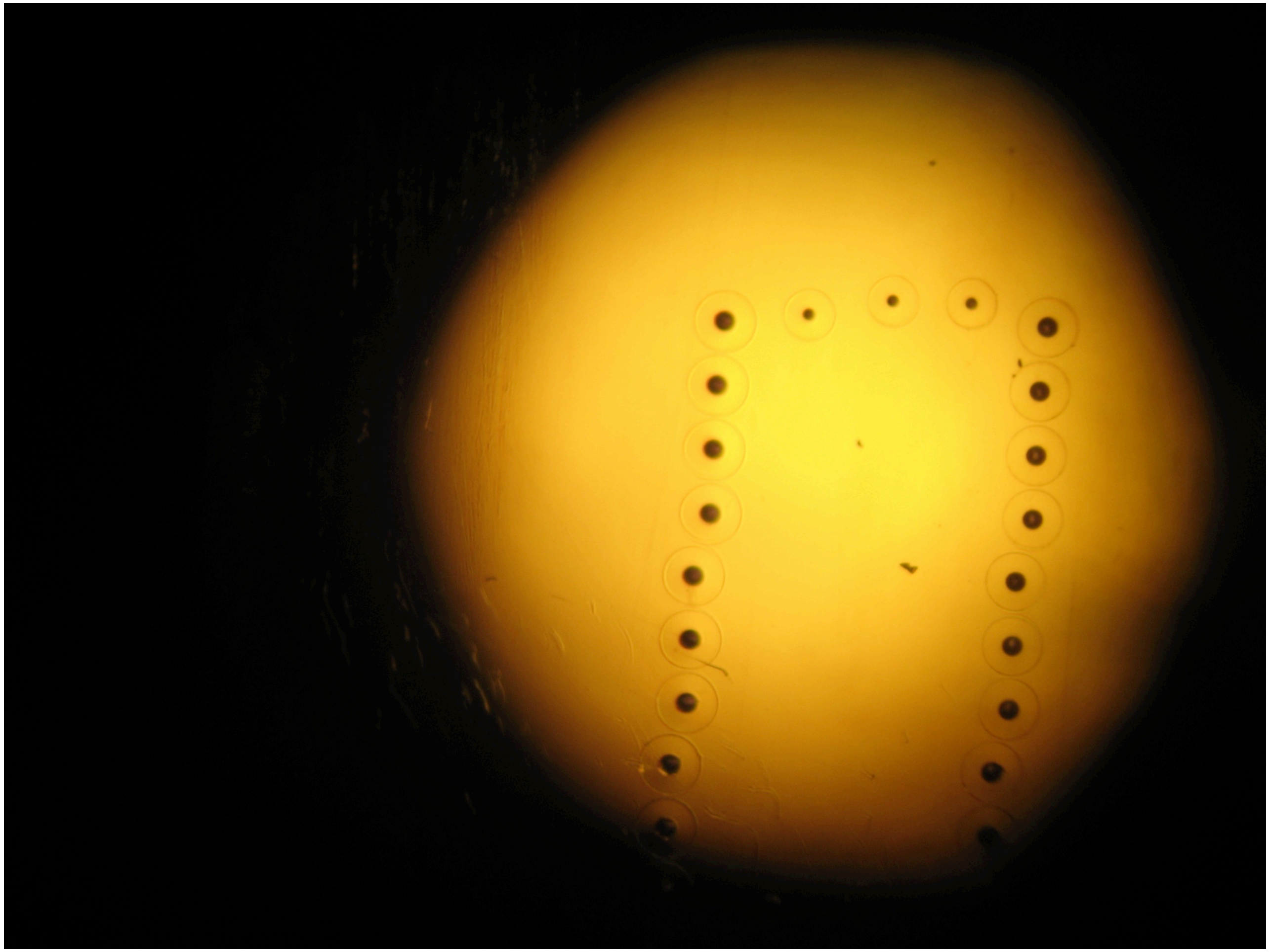
- Geometry parameters of nozzle
  - Diameter
  - Depth
- Effect on droplets
  - Volume
  - Speed
  - Deflection angle
- Effect on ink supply (refilling)
  - Capillary forces
- Fabrication tolerances limit picture quality
- Fabrication of orifice plates
  - Laser-ablation in polyimide, especially for small nozzles (10 pl, 20 um)
  - Nickel-electroplating
  - Electro-discharge machining (EDM)
  - Micro-punching
  - Micro pressing



Electroplated Ni-nozzle



Nozzle design



Cartridge Design

- HP cartridge
  - Bubble generator
  - Accumulator

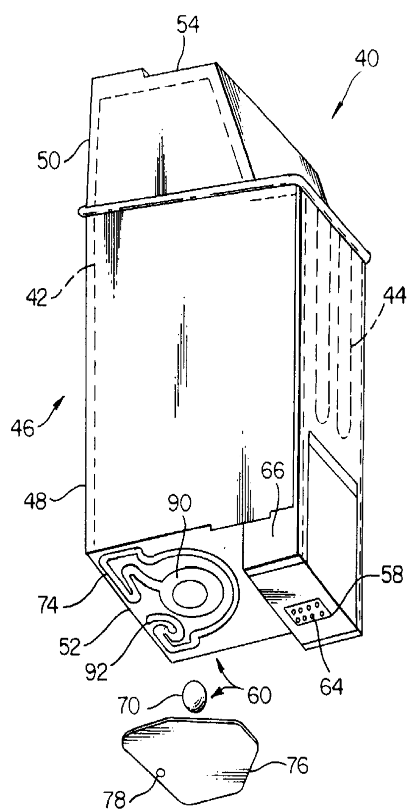
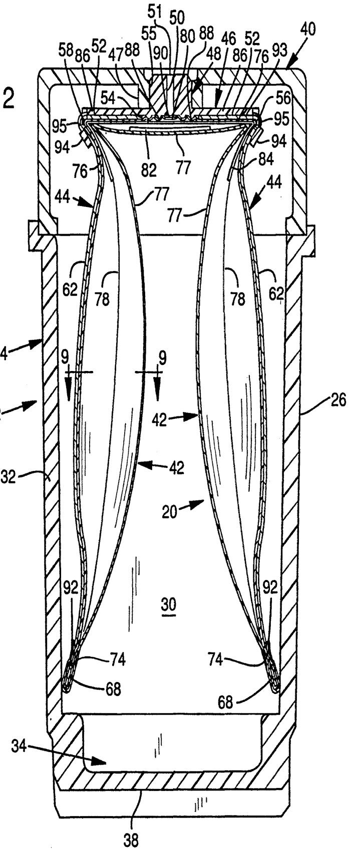


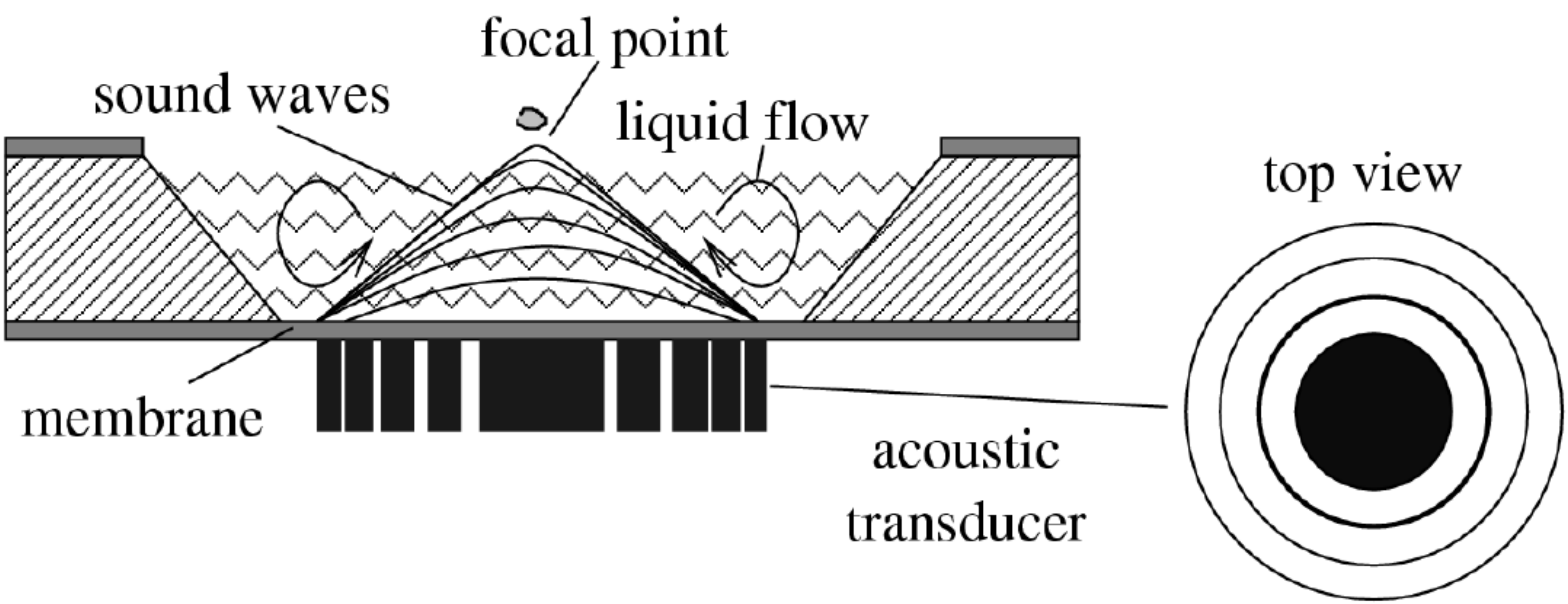
FIG. 2



OTHER TYPES

Ultrasonic droplet generation

- Acoustic transducer
- Constructive interference of waves
  - Similar to Fresnel lens



Valve jet

- Non-contact principle
  - Drop-on-demand
  - Often confused with impulse jet
- Working principle
  - Ink held under pressure
  - Dynamic opening of valve
    - Micro-electromechanical
- Spraying of fine jet

Valve jet

Initial position	NC (Normally closed)
Shot size	From 3 nl
Viscosity range	0.5 – 10,000 mPas (thixotropic)
Accuracy	> 97 % (Dispensing tolerance < 3 %)
Frequency	Up to 280 shots/sec (Hz)
Fluid pressure	0.2 to 6 bar (up to 100 bar)
Operating medium	dry compressed air, oil-free, filtered (filter unit 40 µm)
Operating pressure	4 to 8 bar
Switching time	Starting at 2 ms
Electrical input	24 V, PLC compatible
Service life	> 100,000,000 cycles
Weight	270 g
Ambient temperature	-5 to +40 °C
Actuator	Electropneumatic
Construction	Robust industrial design, class II equipment, splashproof in accordance with IP 65