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## First approach in ink-jet printing

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## First approach in ink- jet printing

V.Conédéra, F. Mesnilgrete, N. Fabre

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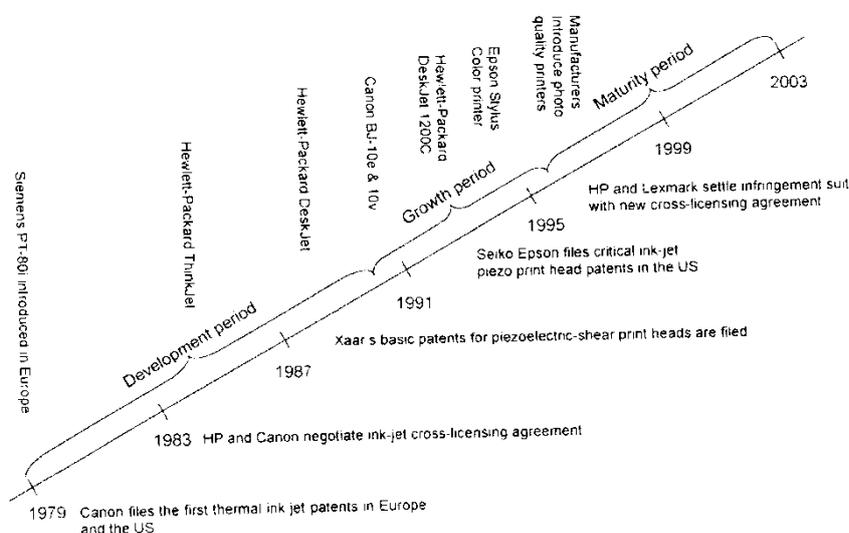
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## I. HISTORY OF THE DEVELOPMENT OF THE INK-JET TECHNOLOGY



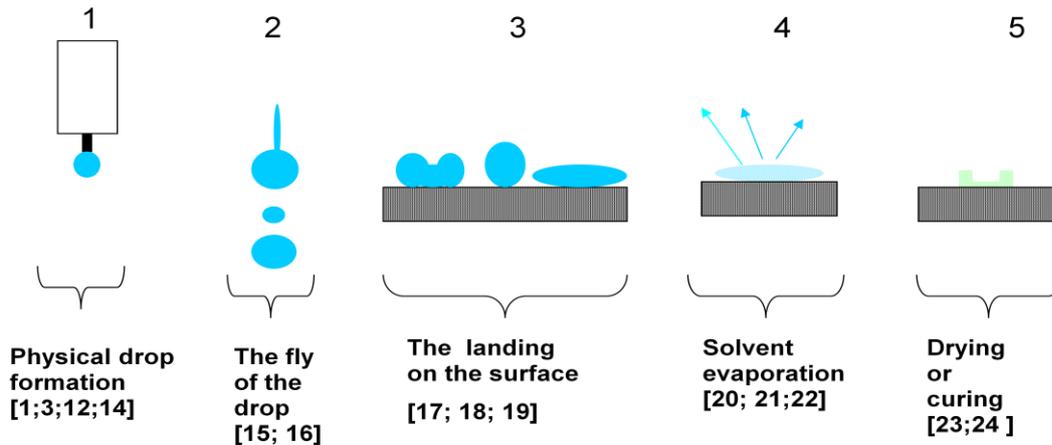
### Three time periods of technological and market development in the ink-jet printing industry

[1] Neil Clymer, Shigeru Asaba, J. Eng. Technol. Manage. 25 (2008) 137-156

3000 patents for 1989-2000 period (Hewlett Packard; Seiko Epson; Canon; Lexmark; Brother; Xerox; Eastman Kodak)

*“ .. ink-jet printing is an incredibly complex technology that appears deceptively simple to the eyes of users*

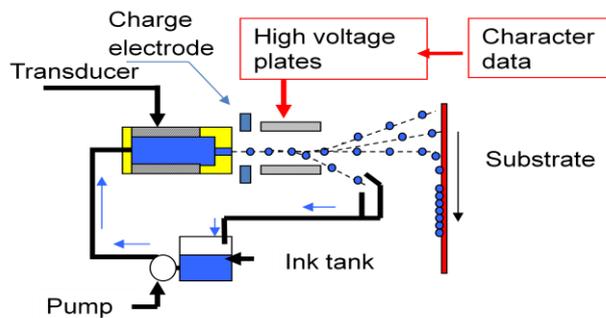
- **Five steps in ink-jet printing**



## II. THE TWO METHODS USED TO PRODUCE DROPLETS

### II.1 Continuous Ink jet (CIJ)

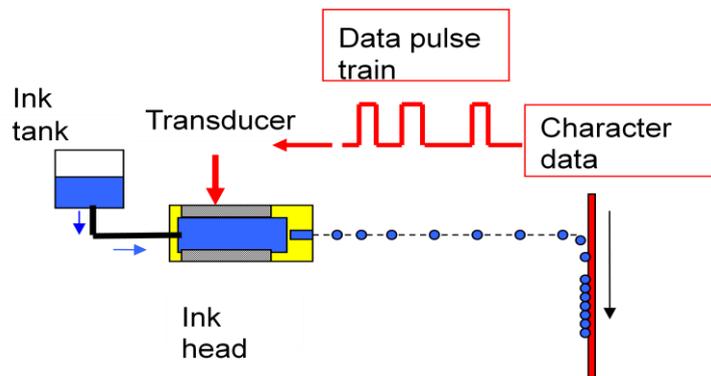
Droplets, in the presence of an electrostatic field, acquire a charge



**Ink must be electrically conducting**

### II.2 Drop on demand (DOD)

Droplets are produced by pressure/velocity transients that are caused by volumetric change, which are induced by a piezoelectric material



**Conductive and not conductive inks**

### III. DROP FORMATION IN PRINT HEADS

**Fromm** obtained an approximate solution to the Navier-Stokes equations to describe droplet formation [4] :

$$Z = \left( \frac{d \rho \gamma}{\eta} \right)^{1/2} = Oh^{-1}$$

$Oh^{-1}$ : Ohnesorge number (dimensionless number)

$\rho$ : density of the fluid

$\eta$ : viscosity of the fluid

$\gamma$  : surface tension of the fluid

$d$  : characteristic length (diameter of the printing orifice)

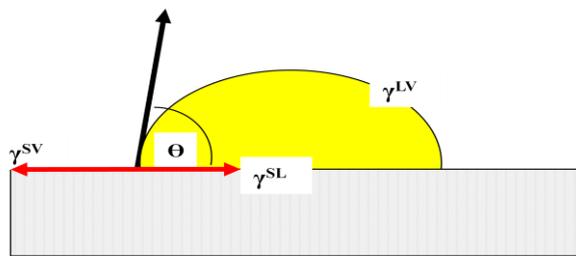
**Fromm** predicted that drop formation in DOD systems was possible for  $Z > 2$

This was latter refined by **Reis** and **Derby** who predicted DOD printing in the range  $1 < Z < 10$  [3]

[3] Nuno Reis, Chris Ainsley and Brian Derby, J. of App. Phys. 97, 094903 (2005)

[4] J.E. Fromm IBM Res. Develop. 28. 3. (1984)

### IV. INFLUENCE OF THE CONTACT ANGLE



If gravitational forces are negligible, a liquid droplet deposited on a substrate will equilibrate to a spherical cap with a contact angle  $\Theta$

#### IV.1 YOUG-DUPRE EQUATION

$$\cos \Theta = \frac{\gamma^{SV} - \gamma^{SL}}{\gamma^{LV}}$$

$\gamma^{LV}$  : Interfacial energy between droplet and air  $Nm^{-1}$

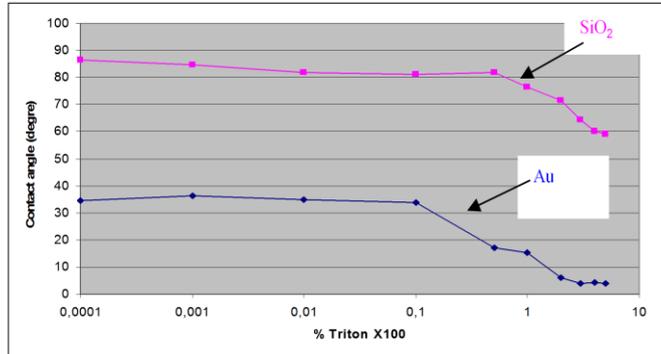
$\gamma^{SV}$  : Interfacial energy between substrate and air  $Nm^{-1}$

$\gamma^{SL}$  : Interfacial energy between substrate and droplet  $Nm^{-1}$

[5] J. Stringer, B. Derby ,and al Journ. Of The European Ceramic Society., 29 (2009) 913-918

## IV.2 CONSEQUENCES

- Substrates with low surface energy (teflon) are  $\Theta$  large and low wettability
- Surfactant addition decrease  $\gamma_{LV}$  and improve the wettability
- Ex: Triton X100 surfactant, mixed in EG, on Au and SiO<sub>2</sub> surfaces (SiO<sub>2</sub> OTS treated)



*Contact angle variation on Au and SiO<sub>2</sub> versus % Triton X100 weight*

[6] V. Conedera, F. Mesnilgrete, M. Brunet, N. Fabre ICQNM Cancun Mexique (1-6 February 2009)

## IV.3 DROPLET IMPACT AND SPREADING

### IV.3.1 Pasandideh-Fard et al (1996) relationship

$$\beta = \frac{d}{d_0} = \left( \frac{We + 12}{3(1 - \cos\theta + 4(We/Re^{1/2}))} \right)^{1/2}$$

$\beta$  : spread factor

$d$  : spread diameter

$d_0$  : initial droplet diameter

$\theta$  : liquid-solid contact angle

$Re$  : Reynolds number =  $\rho v d / \mu$

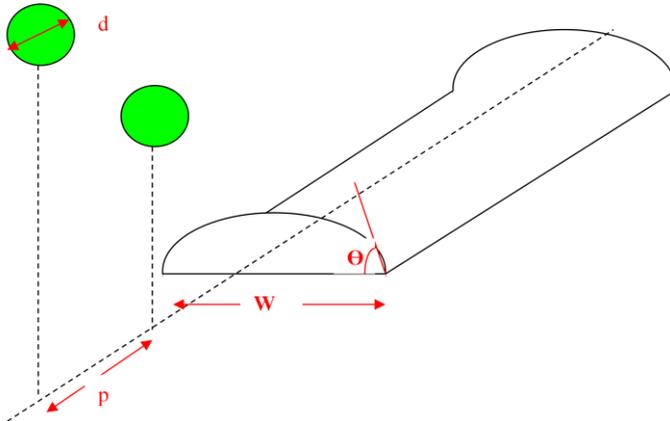
$We$  : Weber number =  $\rho v^2 d / \gamma^{lv}$

### ■ IV.3.2 Other relationship form

$$\beta = \frac{d}{d_0} = \left( \frac{4 \sin \theta (1 + \cos \theta)}{(1 - \cos \theta) (2 + \cos \theta)} \right)^{1/3}$$

[7] Taewoong Lim, Sewoon Han et al Intern. Journ. Of Heat Transfert, 52 (2009) 431-441

#### IV. 4 PREDICTING LINE WIDTH



$$W = \left( \frac{\theta d^3 / 6p}{\theta / 4 \sin^2 \theta - \cos \theta / 4 \sin \theta} \right)^{1/2}$$

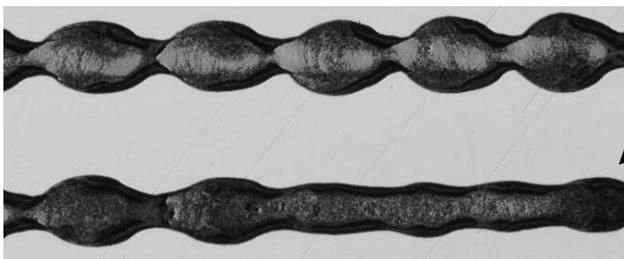
[8] J. Mater.Sci. 2006, 41, 4153

#### IV. 5 INSTABILITY OF PRINTED LINES

$$P_{\max} = \left( \frac{2 \pi d}{3\beta^2 \left( \frac{\theta}{\sin^2 \theta} - \frac{\cos \theta}{\sin \theta} \right)} \right)^{1/2}$$

[9] J.Stringer, B. Derby et al Journ. of the European Ceramic Society , 29 (2009) 913-918

Printed lines can become unstable when the contact angle formed by the liquid with the substrate is larger than the advancing contact angle.



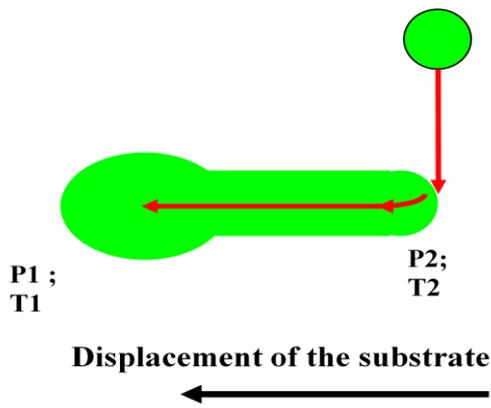
← Unstable printed lines of ZnO nanoparticles deposited on

SiO<sub>2</sub> OTS treated ( $\theta = 90^\circ$ )

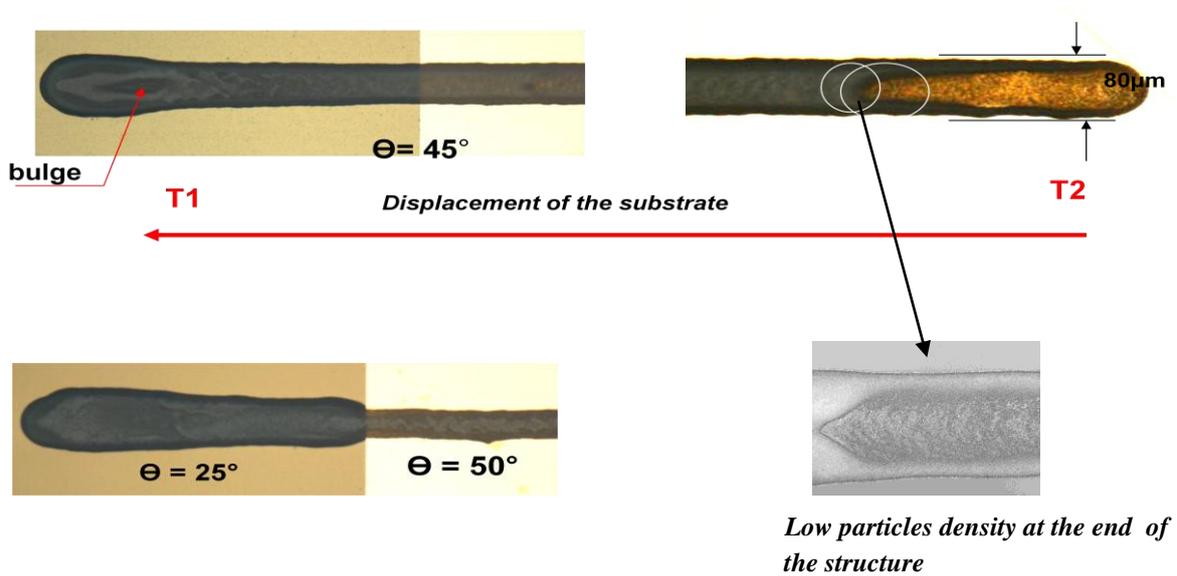
LAAS-CNRS

- **Other phenomena** :at the beginning of the writing
- Material is pumped towards the rear because of the pressure difference which results in bulges being seen

$P1 < P2$  and  $T2 > T1$

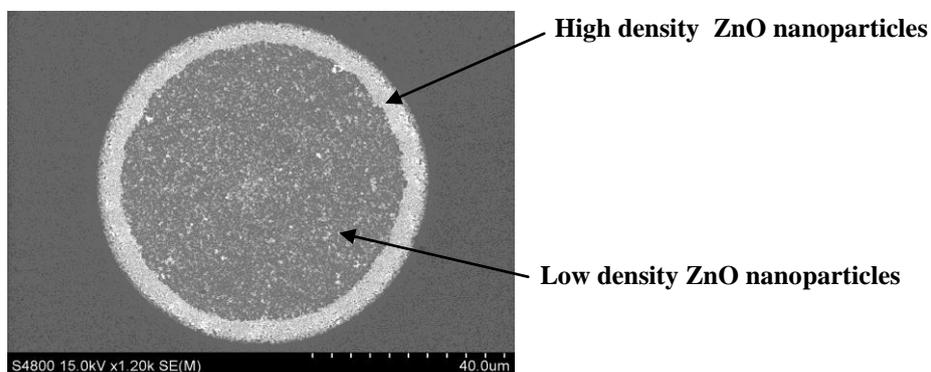


Ex: ZnO deposition: substrate temperature= 110°C; p= 20µm (LAAS-CNRS)



#### IV. 6 COFFEE STAINING

For films we want to print uniform features, but after drying, deposition solute is in an external ring.

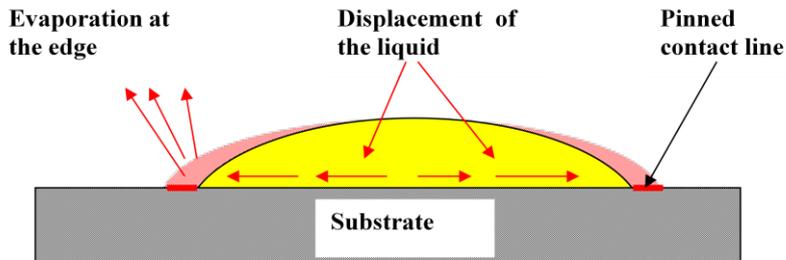


10% ZnO nanoparticle in ethylene glycol, deposited on silicon (10 drops; dried at room temperature)

#### IV.6.1 Deegan theory

The conditions for coffee staining are:

- Volatile and wetting solvent
- Pinned contact line
- Higher evaporation at the edge



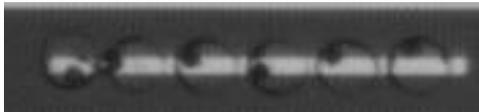
The red area represents the volume of liquid removed by evaporation in a single time step. Since the contact line is pinned any liquid that evaporates from the edge must be replenished by liquid from the interior.

[11] Deegan and al. Phys. Rev. E. , 62 (2000) 756-765

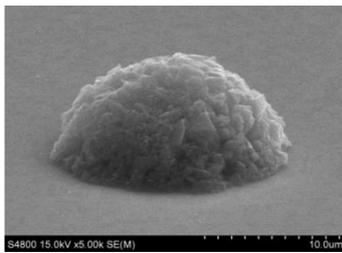
#### IV.6.2 Solutions (or suggestions) to suppress coffee staining

Reducing edge evaporation is a very good approach!

**First:** by increasing the contact angle



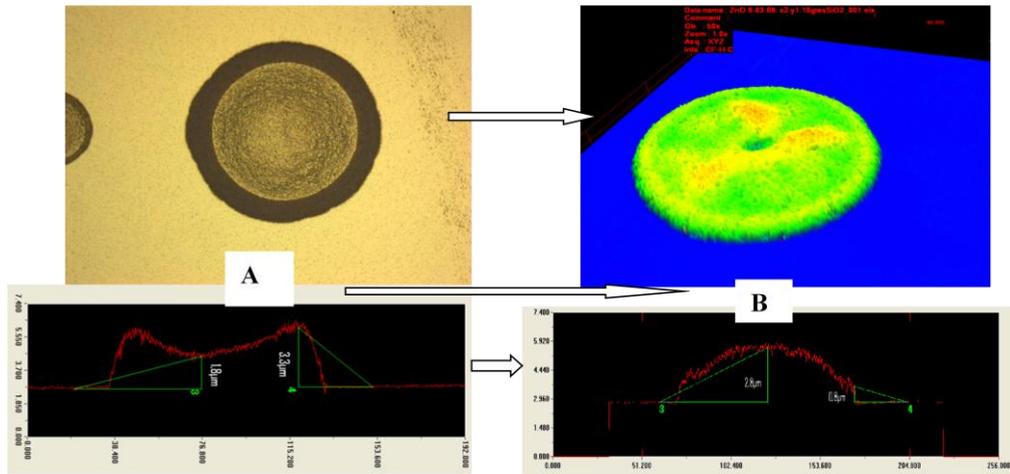
*6 droplets of activated carbon deposited on Au and SiO<sub>2</sub> with 30° contact angle*



*Sessile droplet of activated carbon deposition onto 75° angle surface of SiO<sub>2</sub> (OTS treated)*

[12] V. Conédéra, F. Mesnilgrete, M. Brunet, N. Fabre, ICQNM, 1-6 February 2009 Cancun (Mexico)

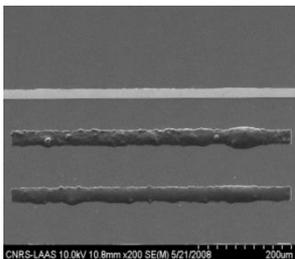
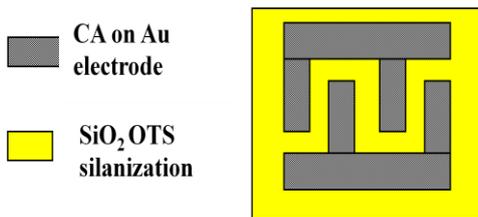
**Second:** by addition of a solvent with high boiling point



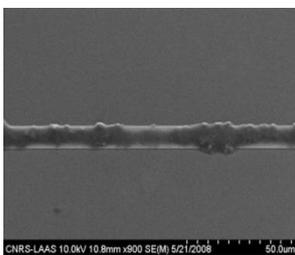
*ZnO profiles : A : 10% ZnO in Ethylene glycol; B: 10% ZnO + 2.5% HBS in Ethylene glycol (LAAS-CNRS)*

**V.1 ACTIVATED CARBON DEPOSITION FOR SUPERCAPACITORS [12]**

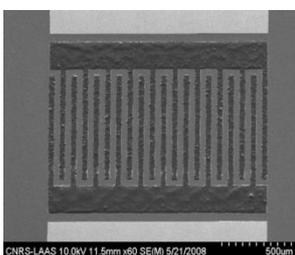
Localisation of the printing on the gold electrodes



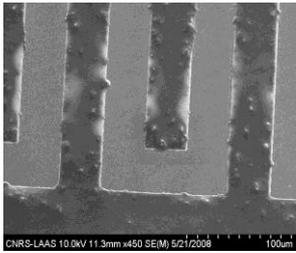
*SEM picture of AC deposited at 140°C onto 30µm wide electrodes*



*SEM picture of AC deposited at 140°C onto 10µm wide electrodes*

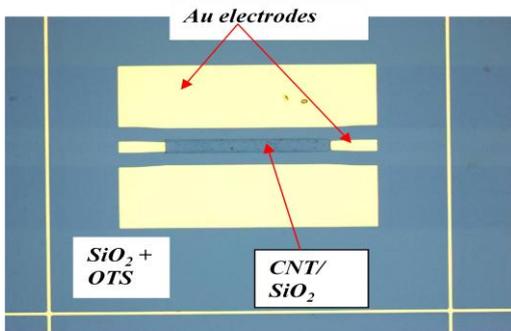


*SEM picture of AC deposited on an interdigitated structure*

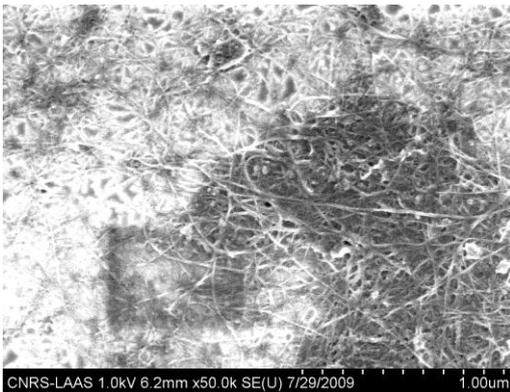


*detail of the structure*

**V.2 Carbon nanotubes for RF applications (first result)**

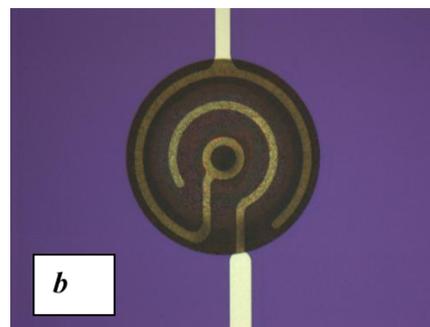
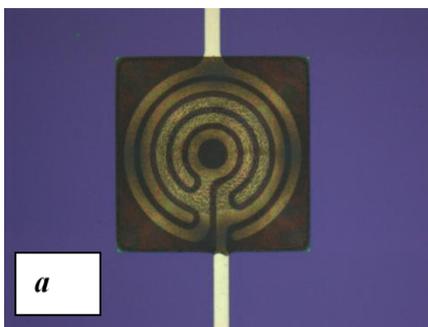


*CNT deposited onto SiO<sub>2</sub> : chemical confinement by OTS*



*SEM of NTC (S. Pacchini LAAS-CNRS)*

**V.3 ZnO nanoparticles for gas detection applications**

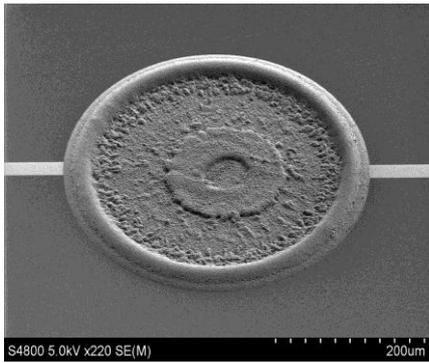


*Gas sensor with (a) square geometry; (b) circular geometry.*

*Conditions of deposition: 30 drops; 50µm diameter of the ink head; substrate temperature 65°C*

*Chemical confinement by OTS*

*Ink composition : 10% ZnO nanoparticles in 2.5% HBS in ethylene glycol ( in weight)*



**SEM gas sensor with circular geometry**

**Conditions of deposition 60 drops; 80 µm diameter of the of the ink head; substrate temperature: 130°C**

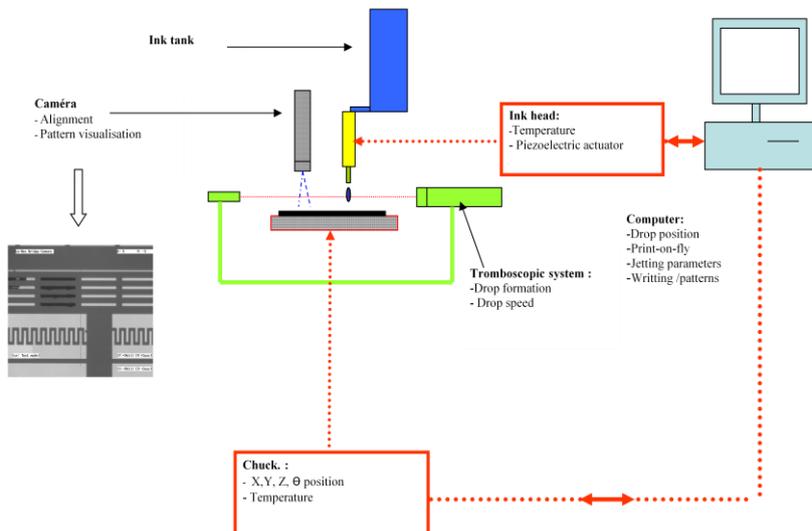
**Ink composition: 10% ZnO nanoparticles in ethylene glycol (in weight)**

[13] V. Conedera, P. Yoboue, F. Mesnilgrete, P. Menini, N. Fabre, SPIE January 2010 (submit)

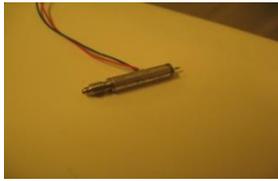
**VI. THE ALTADROP EQUIPMENT**



**Overview**



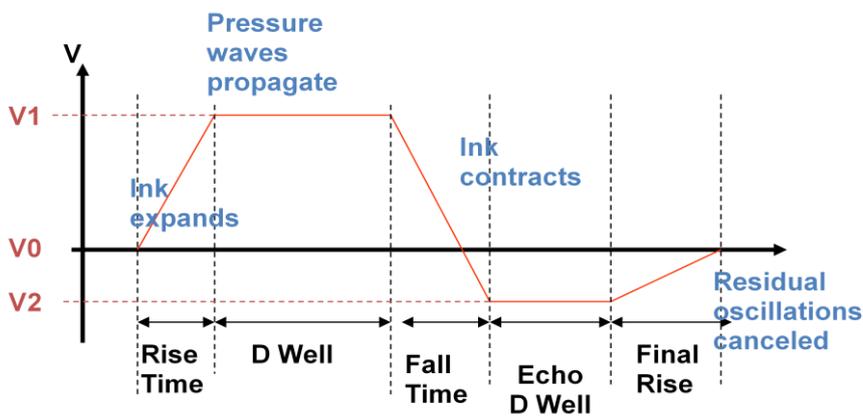
## Ink heads



MicroFab print head



Squeeze piezoelectric actuator



*Piezoresistive actuator : Wave form  
12 000 combinations possible!*



### Ink fabrication : the challenge!!

- **Viscosity** : above 40mPa.s, jetting becomes difficult
- **The quality of suspensions:**
  - Stability with time
  - No agglomeration
- **Chemical compatibility** with ink head, pipes and valves...
- **Adequation with the substrate....**

## VII. CONCLUSION

**Do you remember:**

*... ink-jet printing is an incredibly complex technology that appears deceptively simple to the eyes of users!!”*

**aim :**

*“it’s an exciting subject !!”*

### ADDITIONAL REFERENCES

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