

Failure Modes in Capillary Self-Assembly

M. Mastrangeli, J. Brugger

STI / IMT / LMIS1

Ecole Polytechnique Fédérale de Lausanne

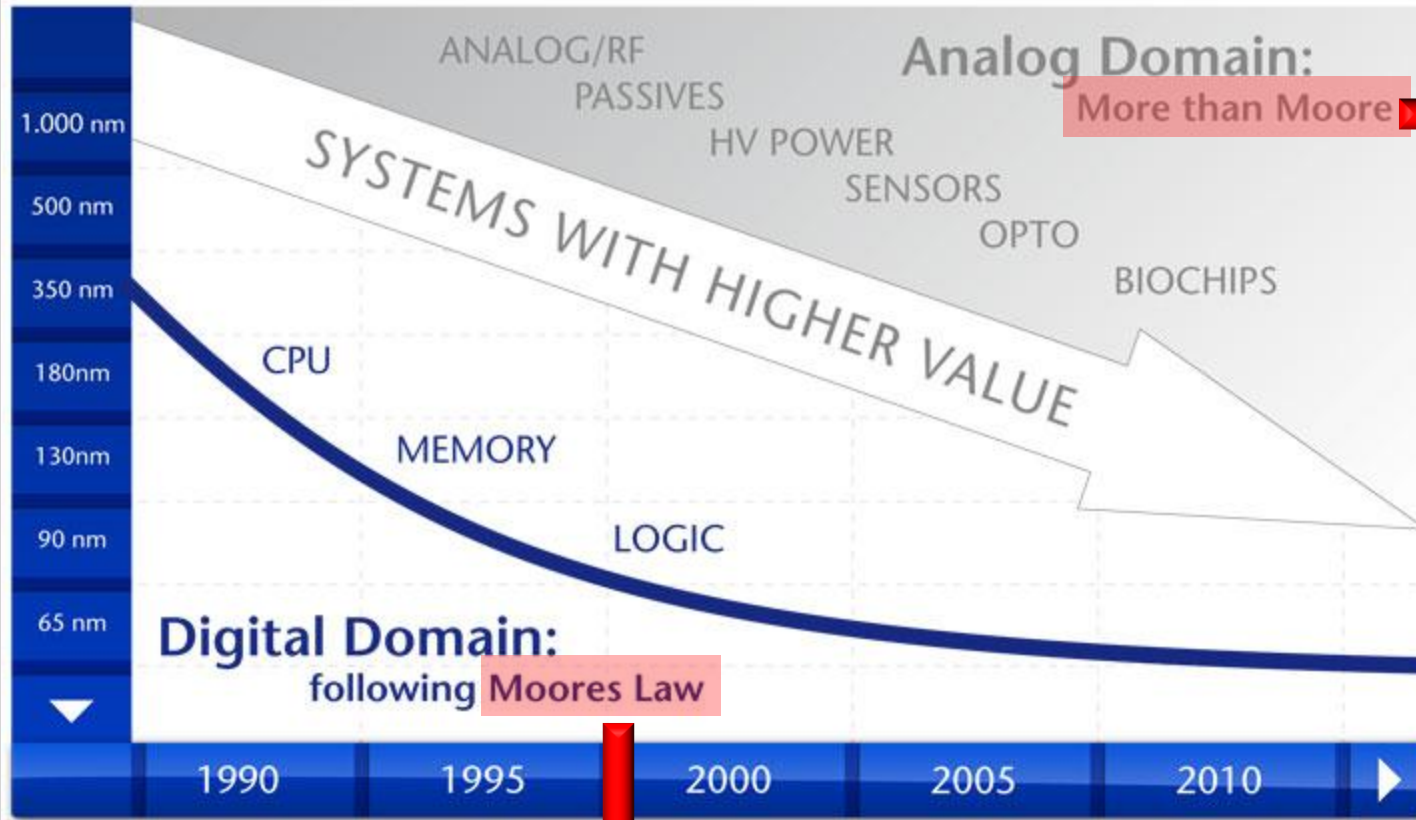
Micromanipulation for Micro and Nanosystems

Femto-ST, Besançon, 11 April 2012

Outline

1. Heterointegration for *More than Moore*
2. *Key*: Capillary Self-Alignment
3. Failure Modes in Capillary Self-Assembly
4. Hybrid Microhandling
5. Conclusions and Perspectives

Miniaturization vs. Diversification



Ever richer:
*"All in one,
one for all"*

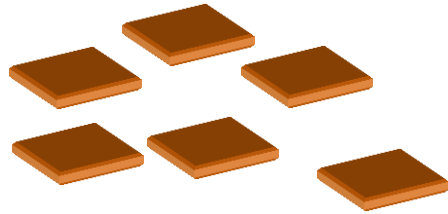
Integrated
systems

**Monolithic
VS
heterogeneous**

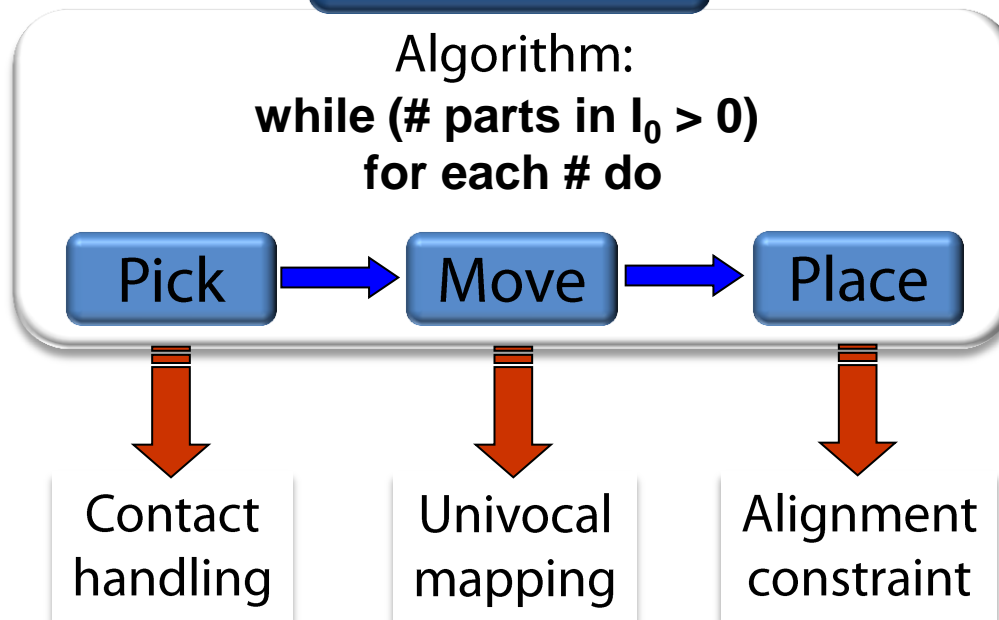
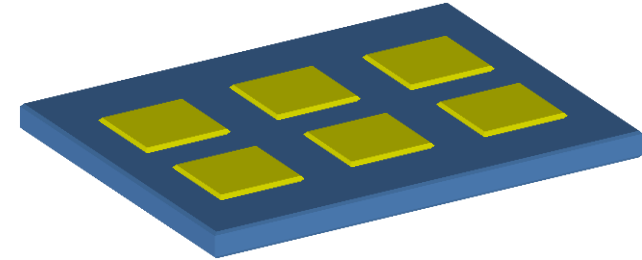


Ever smaller:
"There's plenty of Boole at the bottom"

Heterointegration: Pick & Place



PICK & PLACE



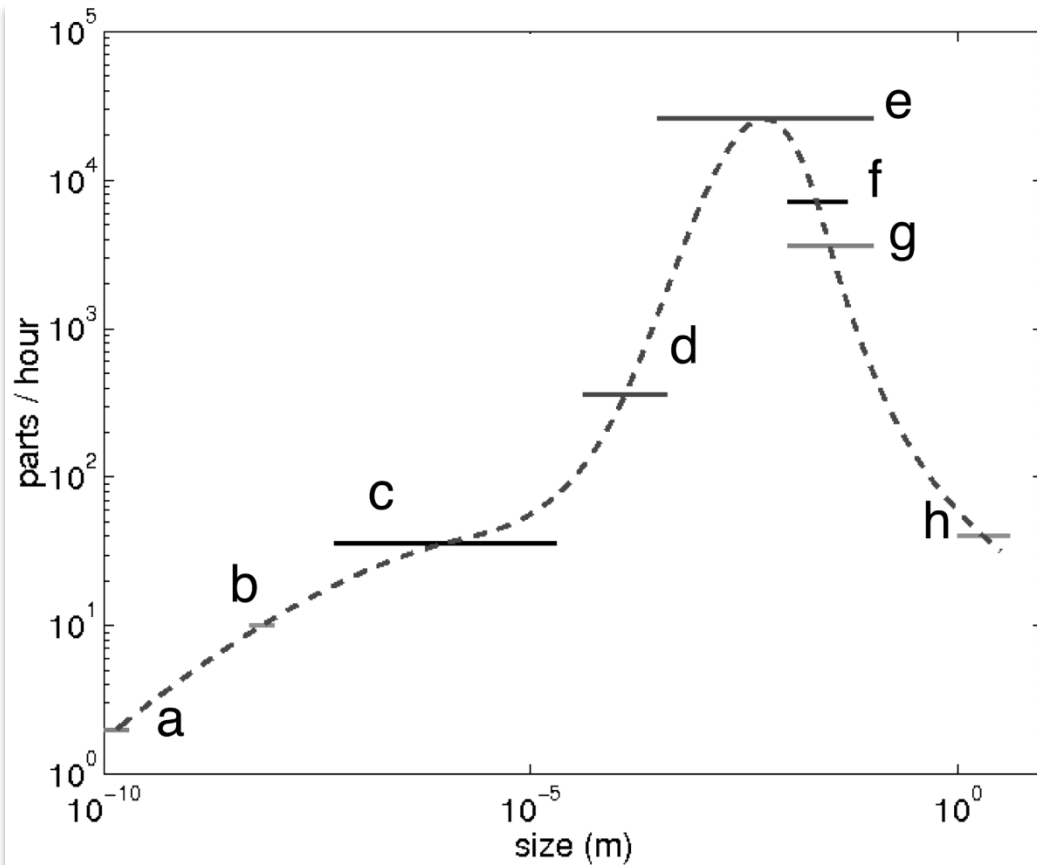
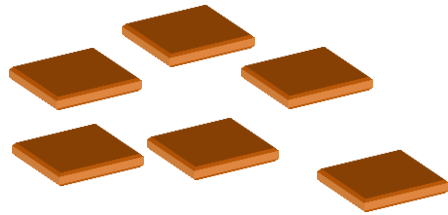


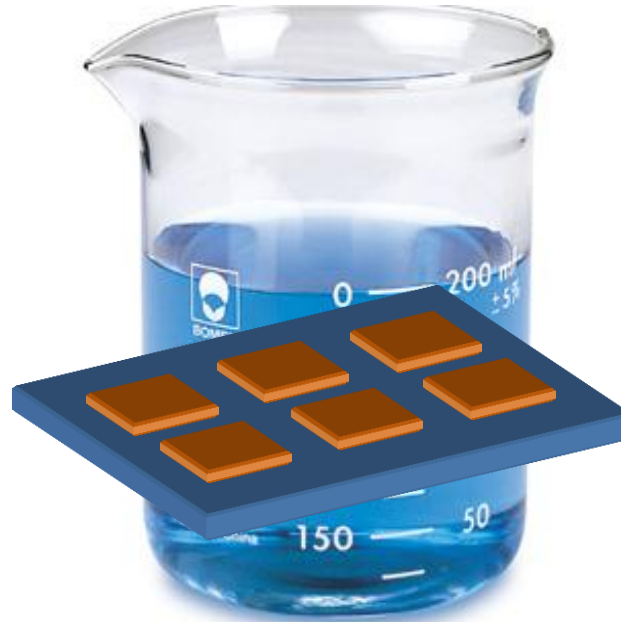
Fig. 1. Approximate speed (parts per hour) versus approximate range of part size for a variety of serial assembly methods. The enclosed zone identifies the area in which self-assembly can have significant contributions. Sources are as follows: a, individual atom placement by STM [2]; b, polymer memory storage device [3]; c, optical tweezers assembly [4]–[6]; d, 3-D microassembly [7]; e, robotic pick-and-place printed wiring board assembly (model HLX8100, Essentec, Switzerland); f, robotic assembly of a grease gun coupler (Innovation, Inc., Birmingham, AL); g, robotic assembly of automobile wheel bearings (Capitol Technologies, Inc, Niles, MI); h, robotic assembly of an automobile body and chassis (Profibus International case study: OPEL Germany).

Morris et al.,
IEEE T. Adv. Pack. 28 (4), 2005

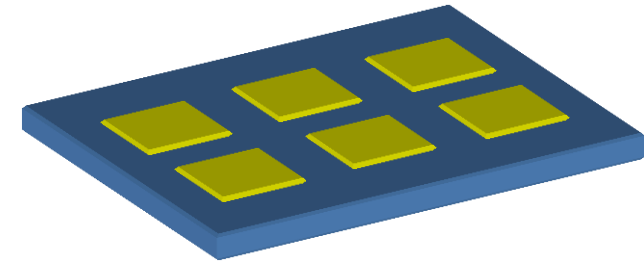
Heterointegration: Self-Assembly



Initial set of parts (I_0)



Parallel



Target substrate = **template**

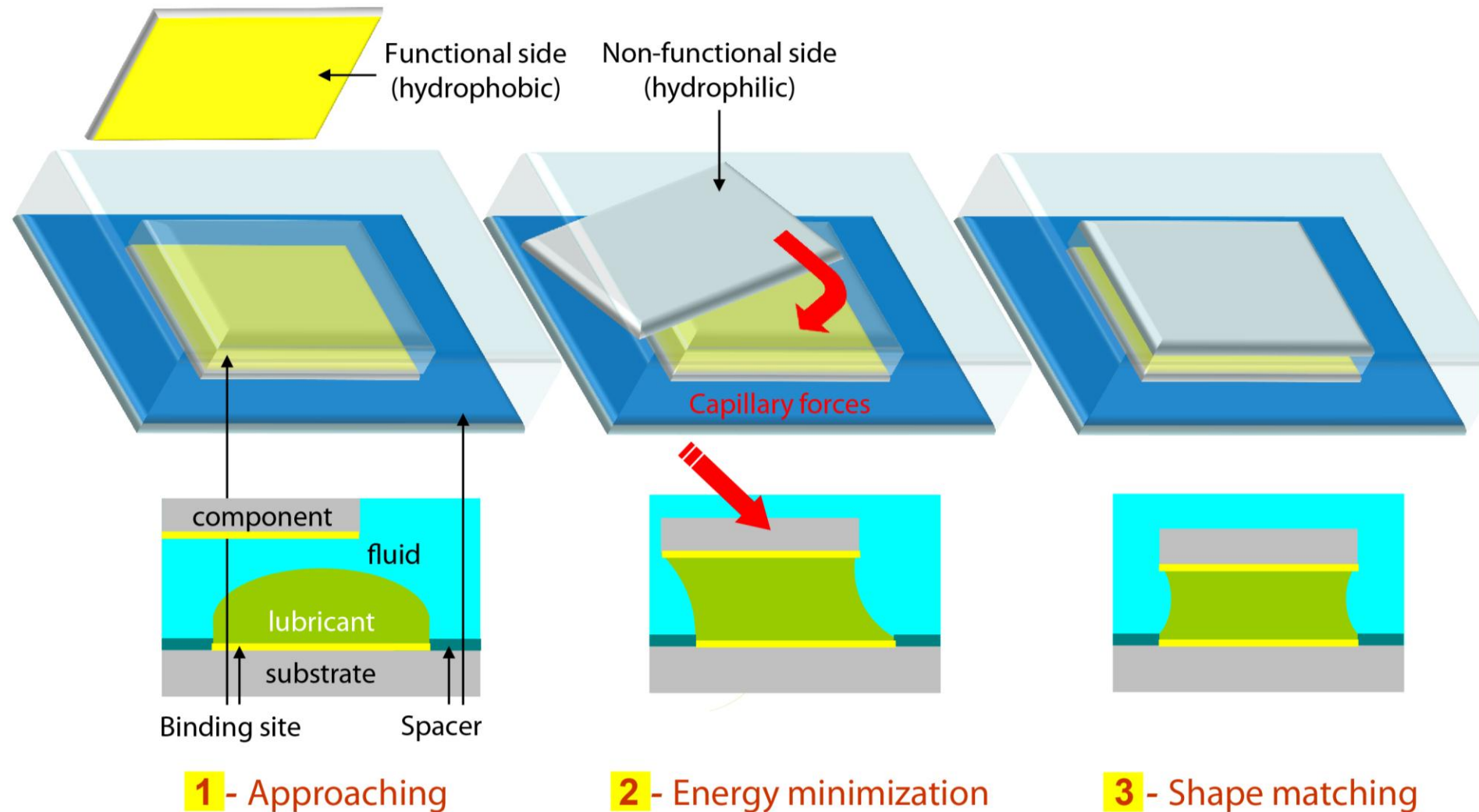
Unsupervised

Non-contact
handling

Stochastic
mapping

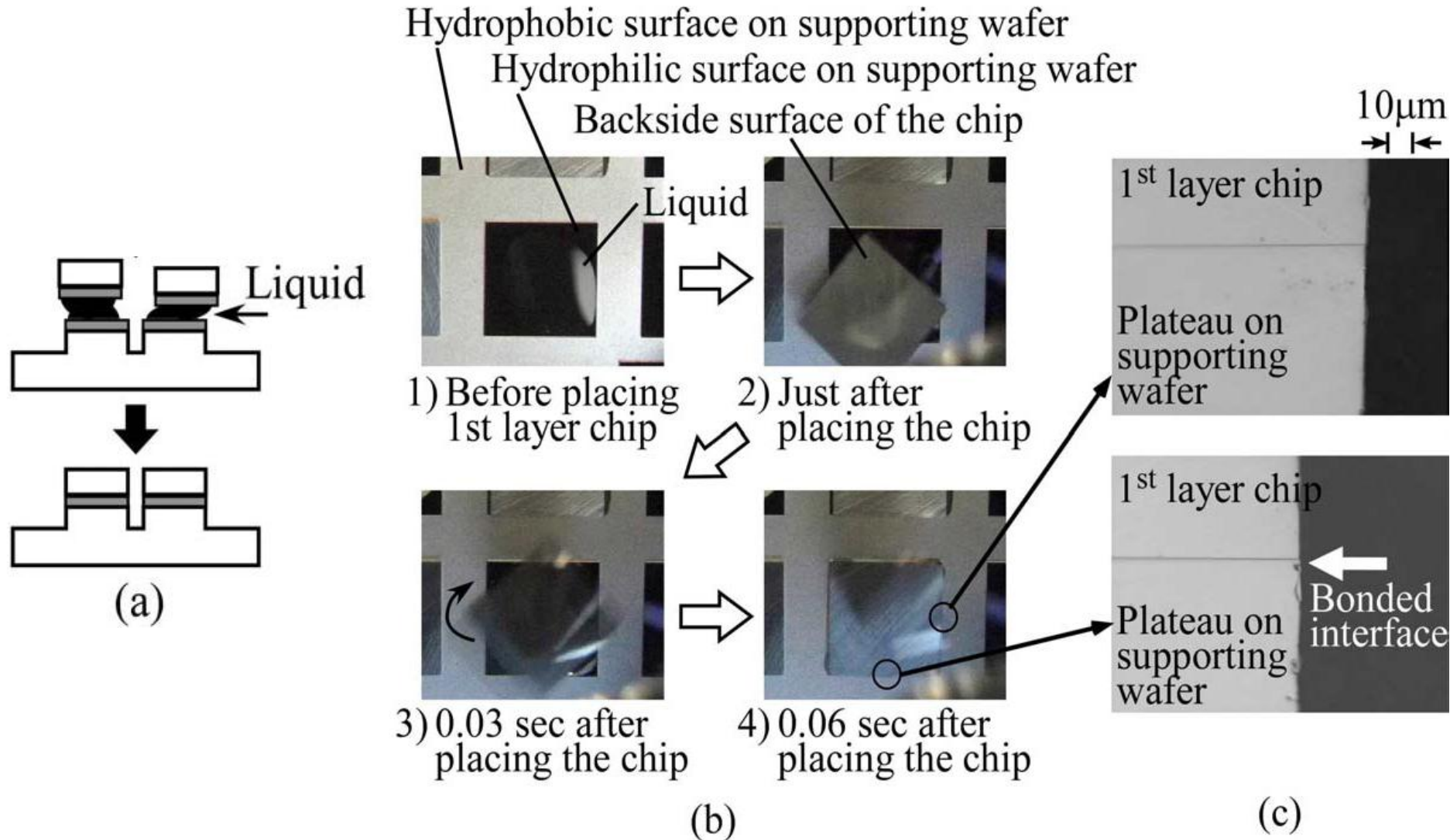
Alignment
constraint

Capillary Self-Alignment is the Key



Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

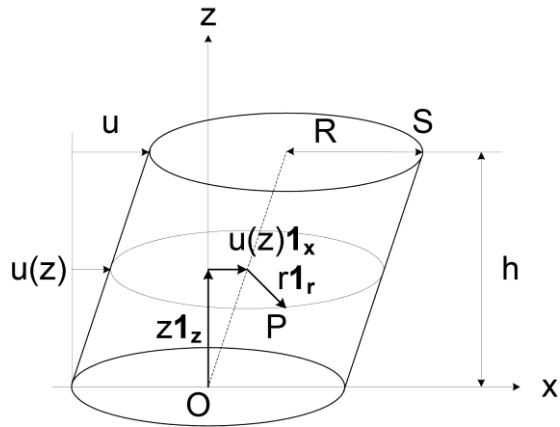
Capillary Self-Alignment is the Key



Fukushima *et al.*, IEDM 2005

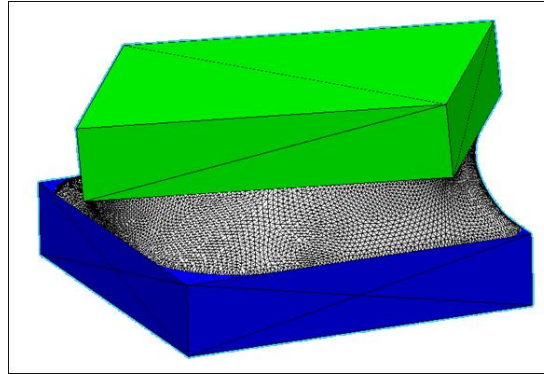
Lateral Capillary Forces

Analytic



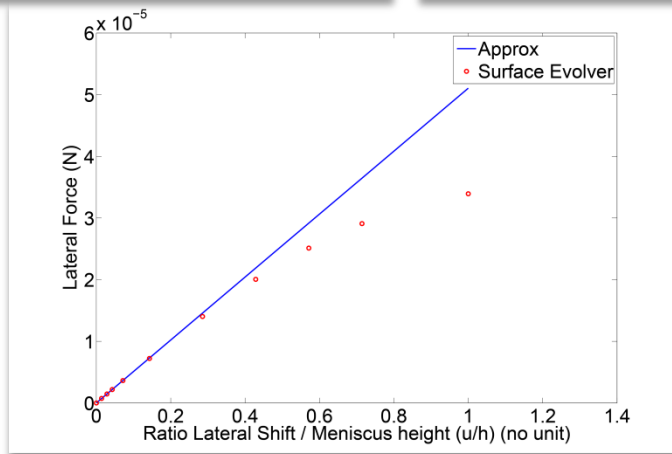
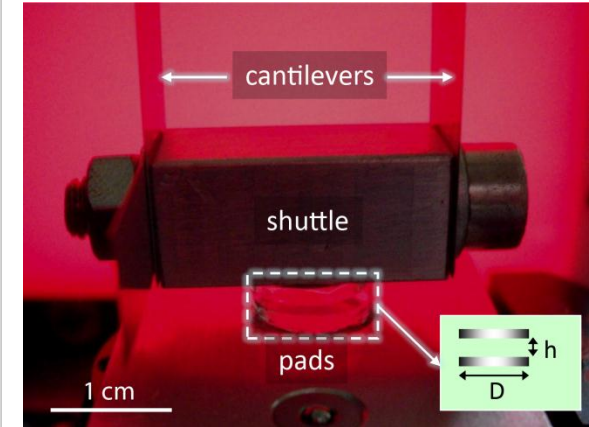
$$F = -\pi R \gamma \frac{u}{h}$$

Numerical

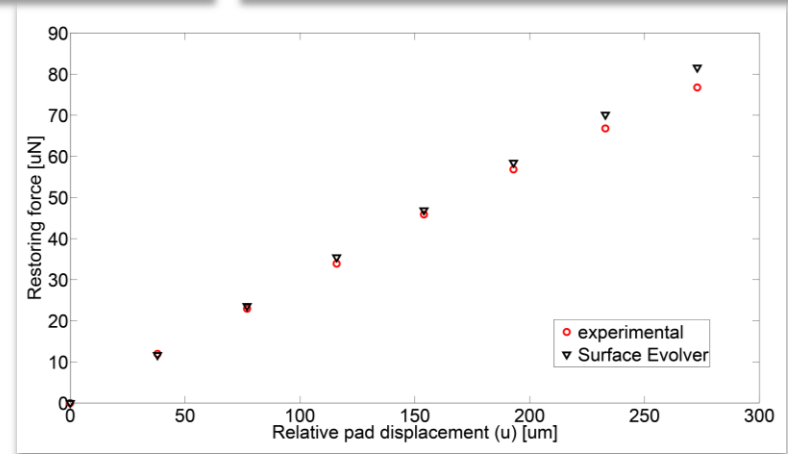


Surface Evolver

Experimental



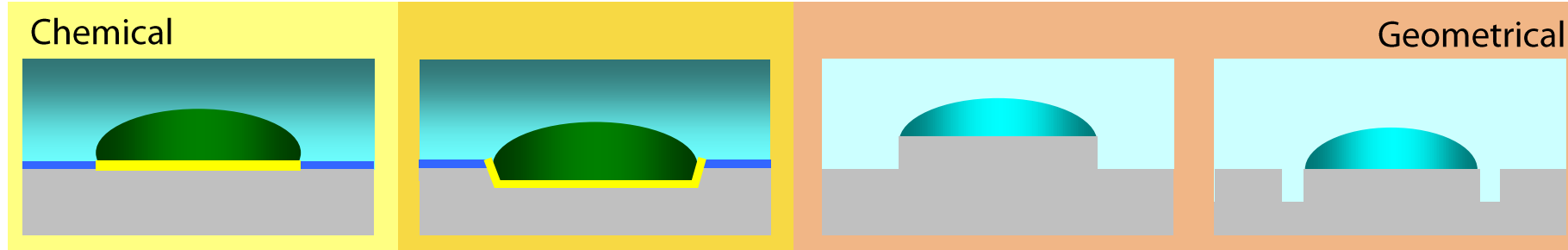
Lambert *et al.*, *Microfluid. Nanofluid.* 9 (2010)



Mastrangeli *et al.*, *JMM* 20 (2010)

Failure Modes - 1

Substrate conditioning and lubricant confinement

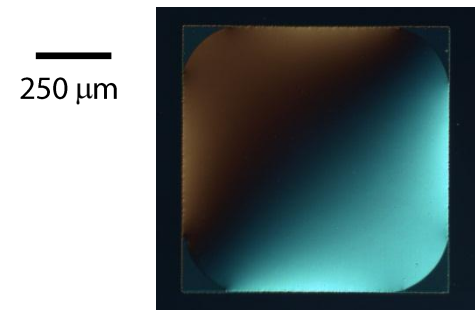


SITES Superficial

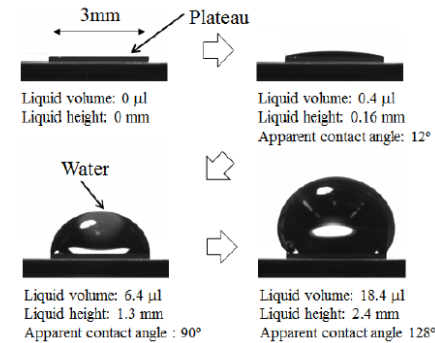
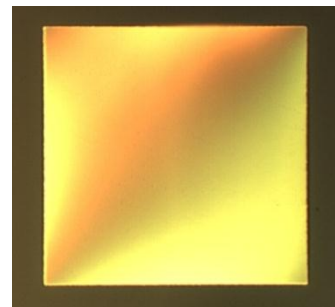
Recessed

Mesa

Threnced



Mastrangeli *et al.*,
JMM 19 (2009)



Takafumi *et al.*,
Micromachines 2 (2011)



- Position
- Volume

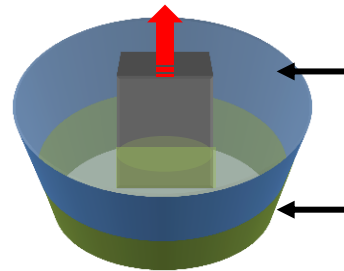
Mastrangeli *et al.*, *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

Failure Modes - 1

Substrate conditioning and lubricant confinement

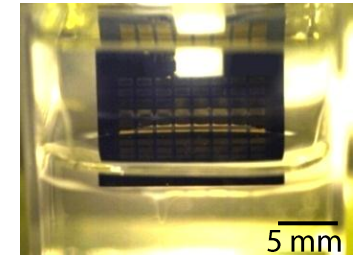
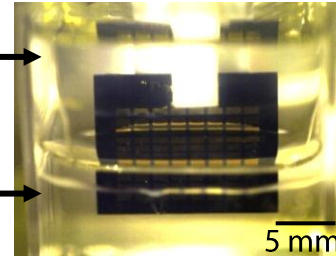
- Dip-coating
 - ✓ Parallel
 - unprecise

vertical sliding



water

lubricant



COATING

- Jetting
 - ✓ Precise
 - Serial

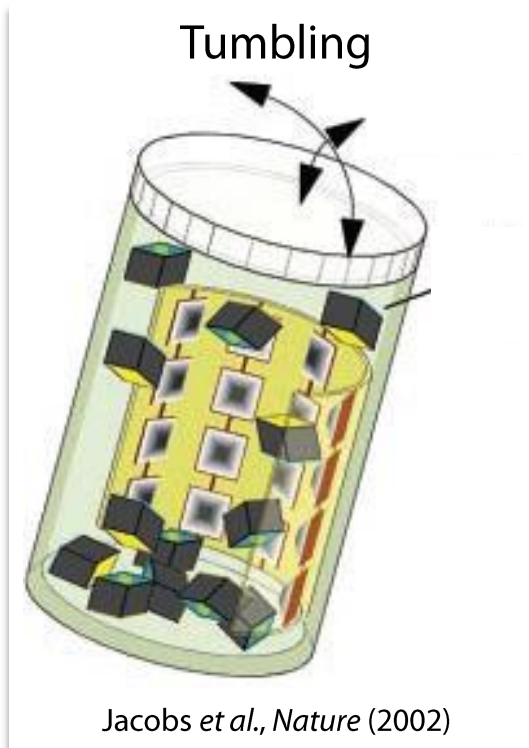


- Position
- Volume

Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

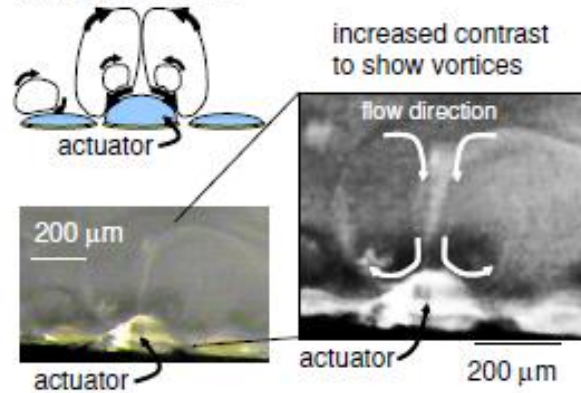
Failure Modes - 2

Part transport and stirring



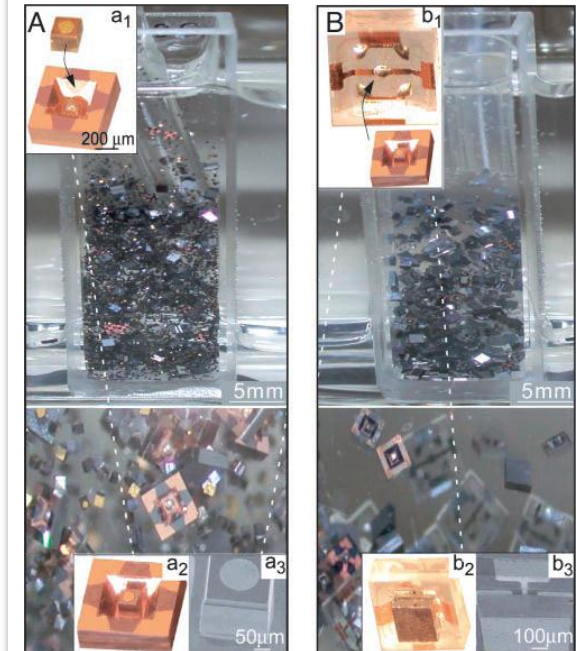
ILEM (Marangoni actuation)

vortices induced by Marangoni effects



Morris & Parviz, *JMM* (2006)

Turbulent pulsating flow



Zheng *et al.*, *PNAS* (2005)

- *Relative part motion*

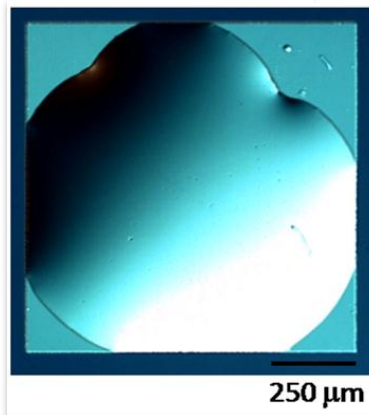
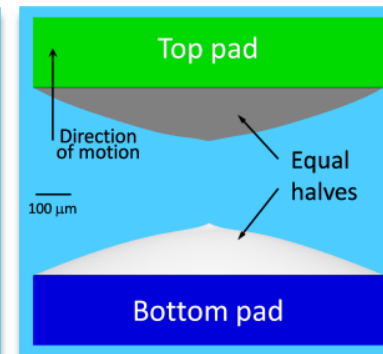
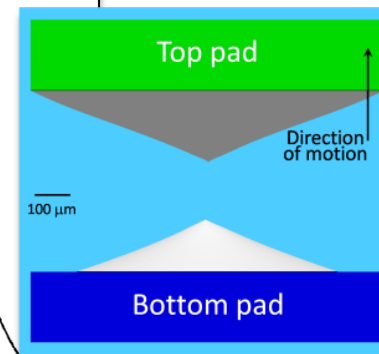
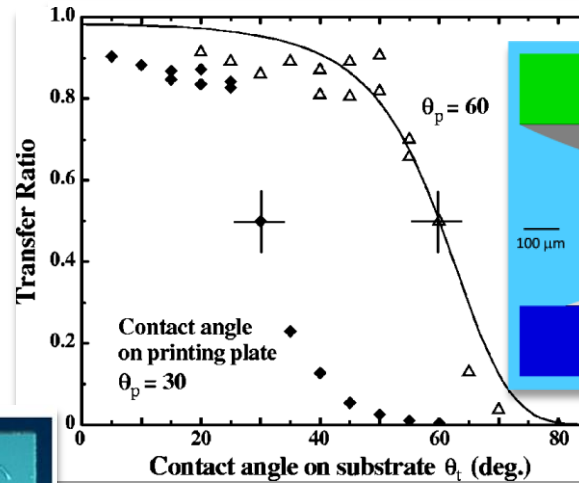
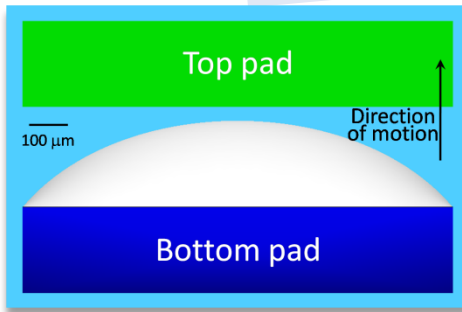
Failure Modes - 3

Assembly correction

Selective removal of wrongly-assembled parts

ideal

real

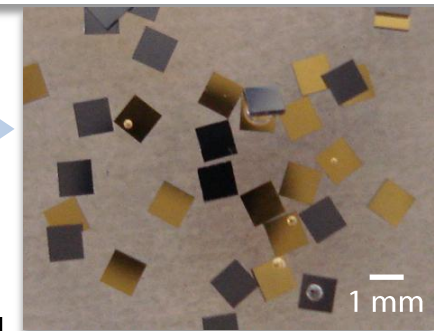


Darhuber et al., *J. Appl. Phys.* (2001)

velocity →

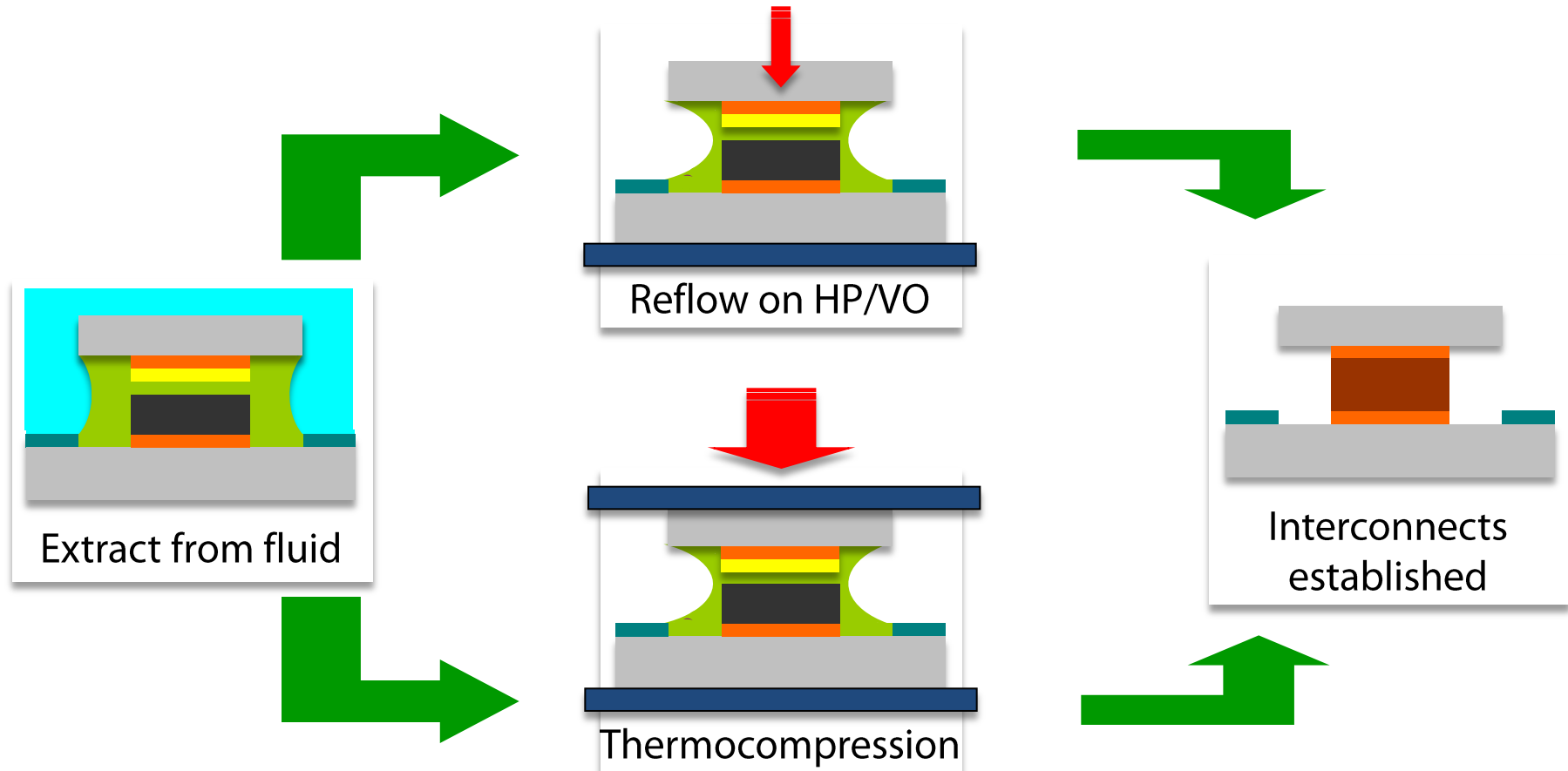
Coating perturbation

Mutual part binding



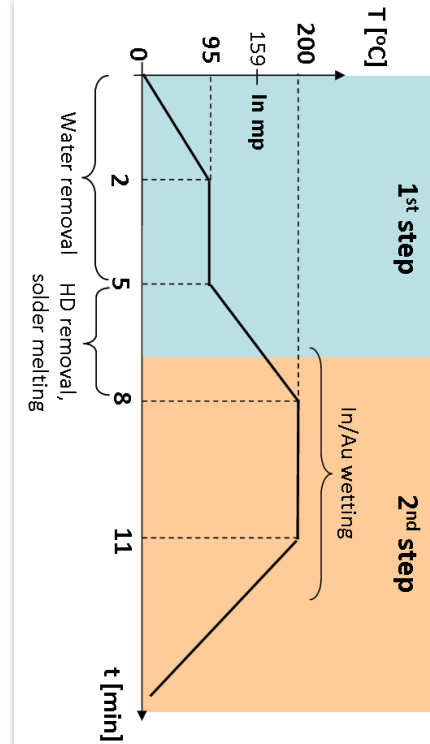
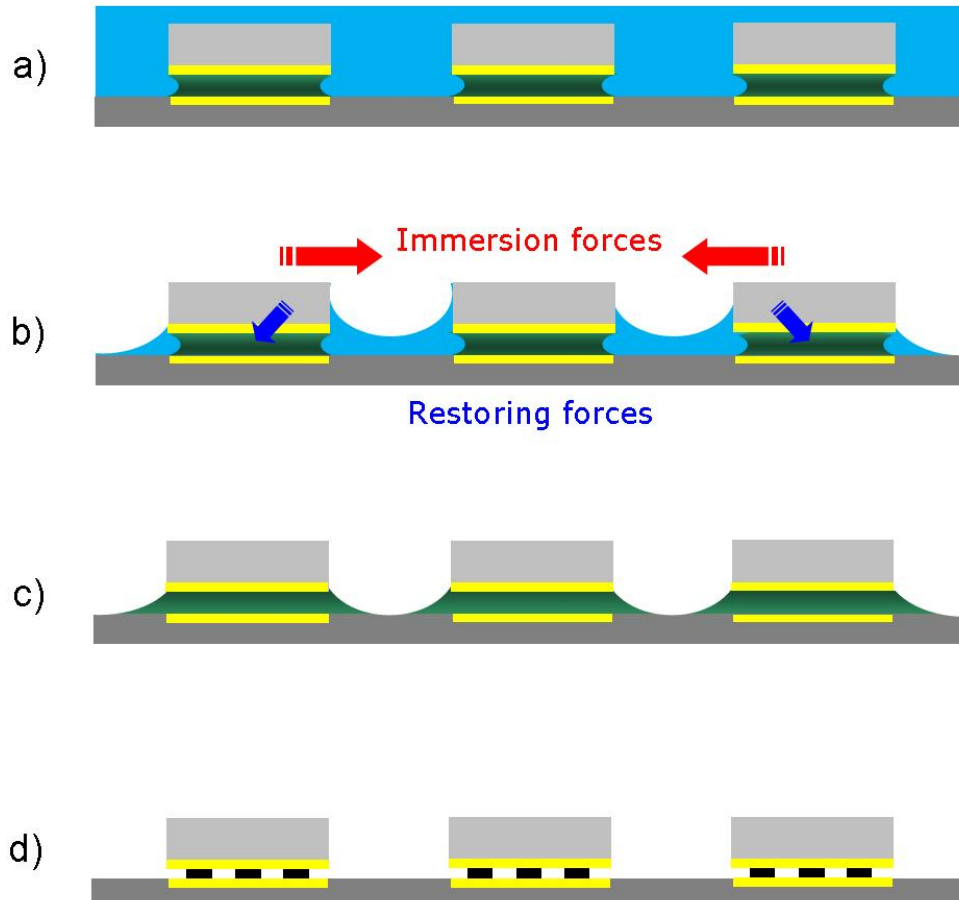
Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

Options



Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

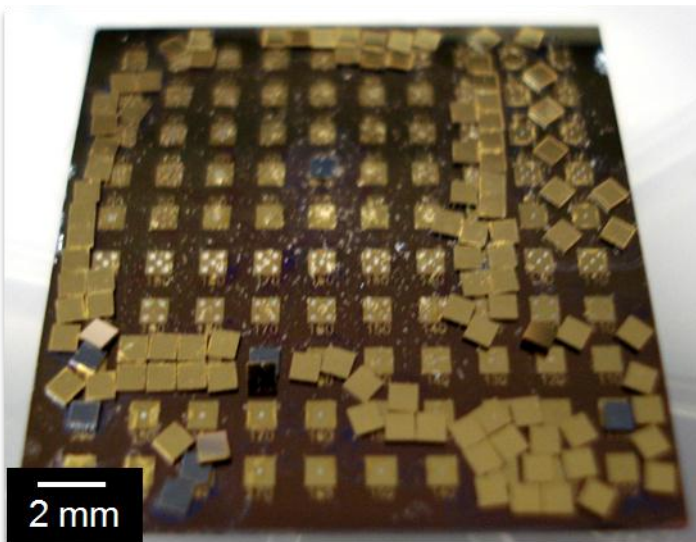
Steps



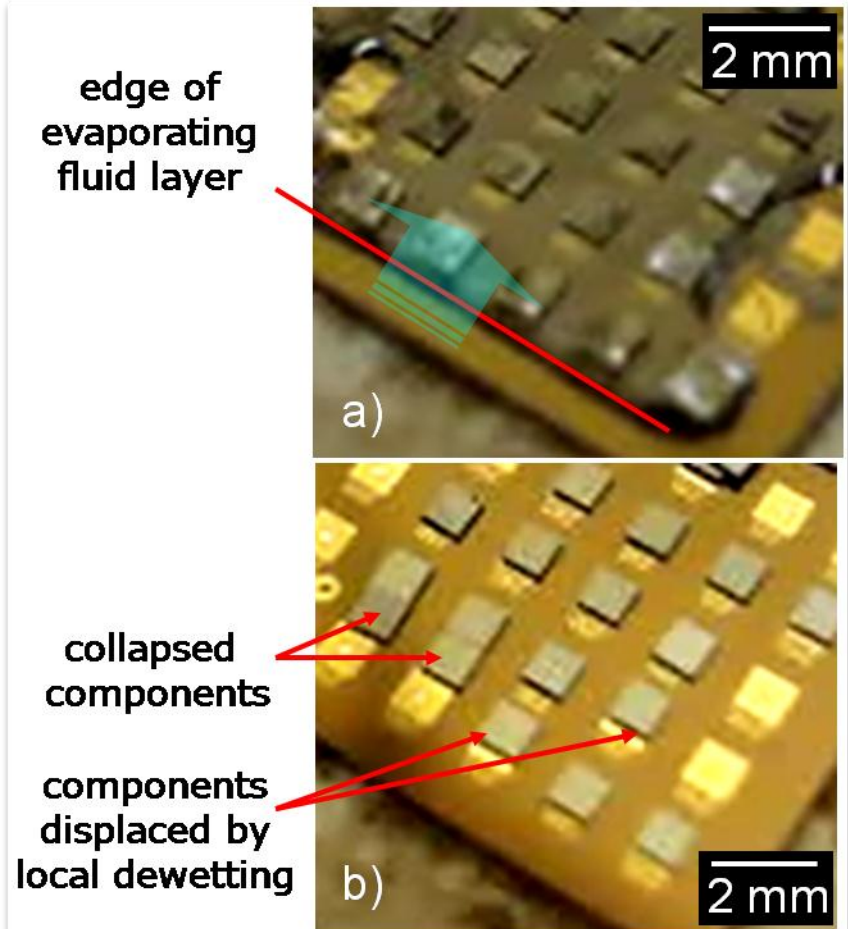
Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

Reflow: effects - 1

Assembly disruption



Capillary aggregation

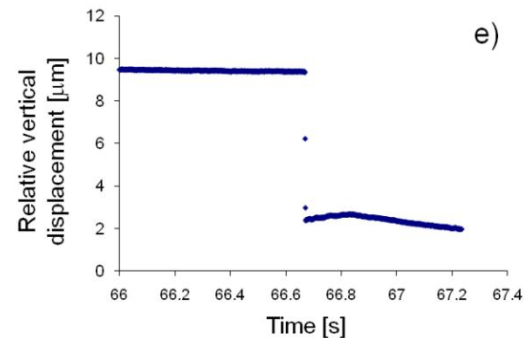
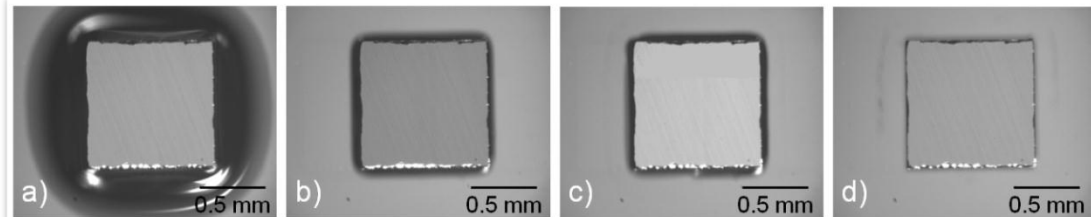
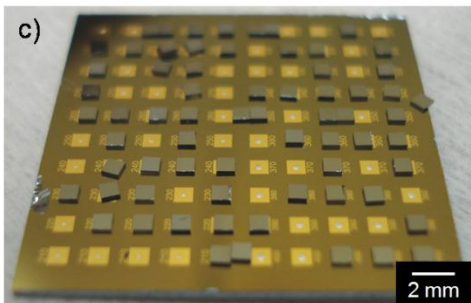
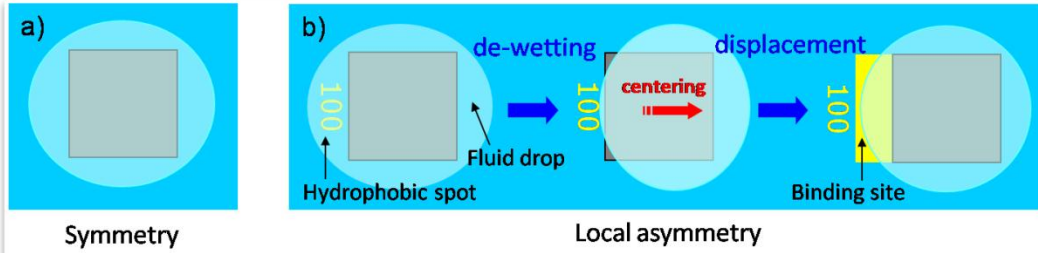


Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

Failure Modes - 5

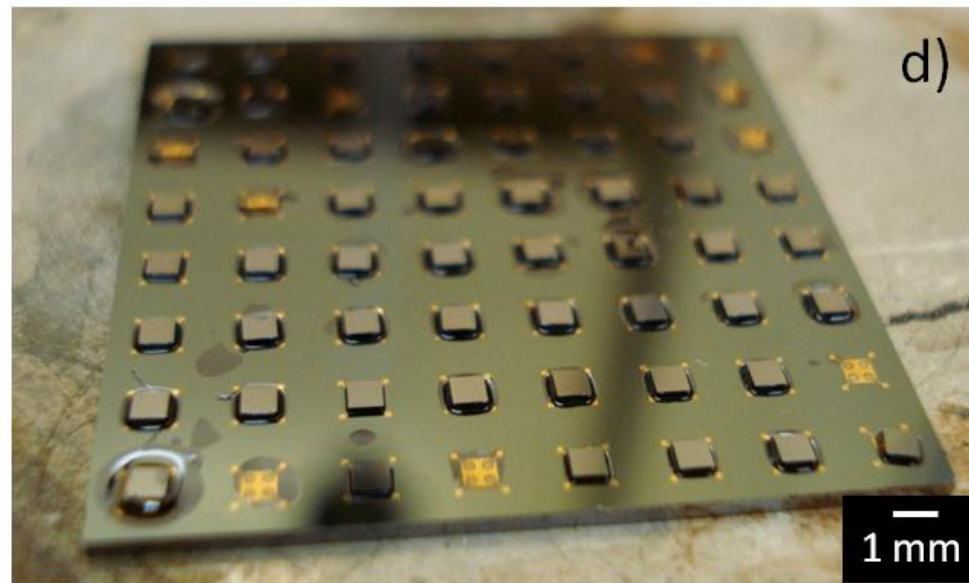
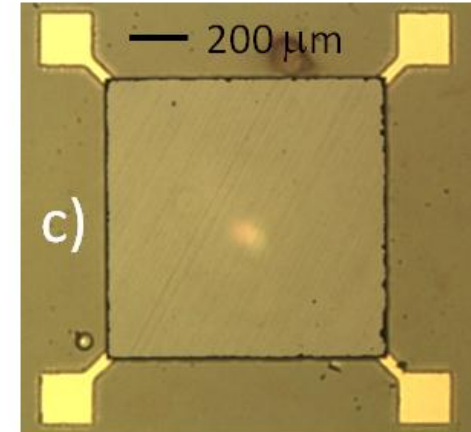
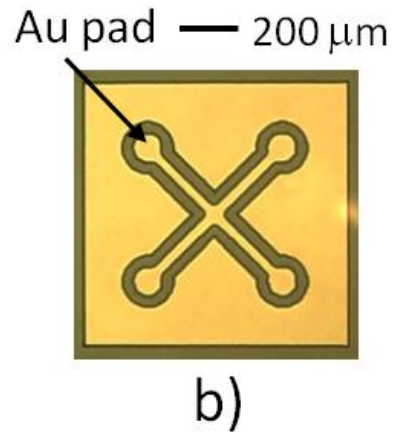
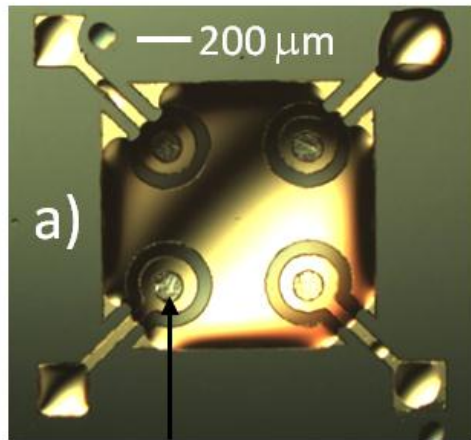
Reflow: effects - 2

Capillary de-centering



Free fall

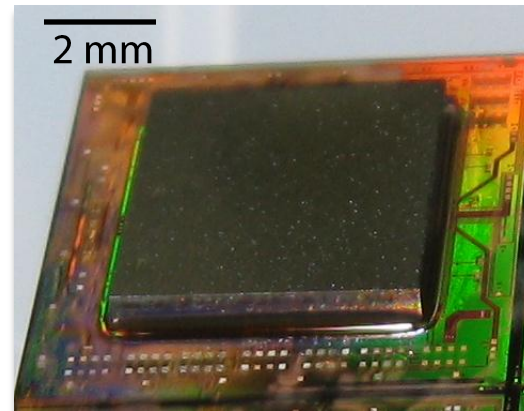
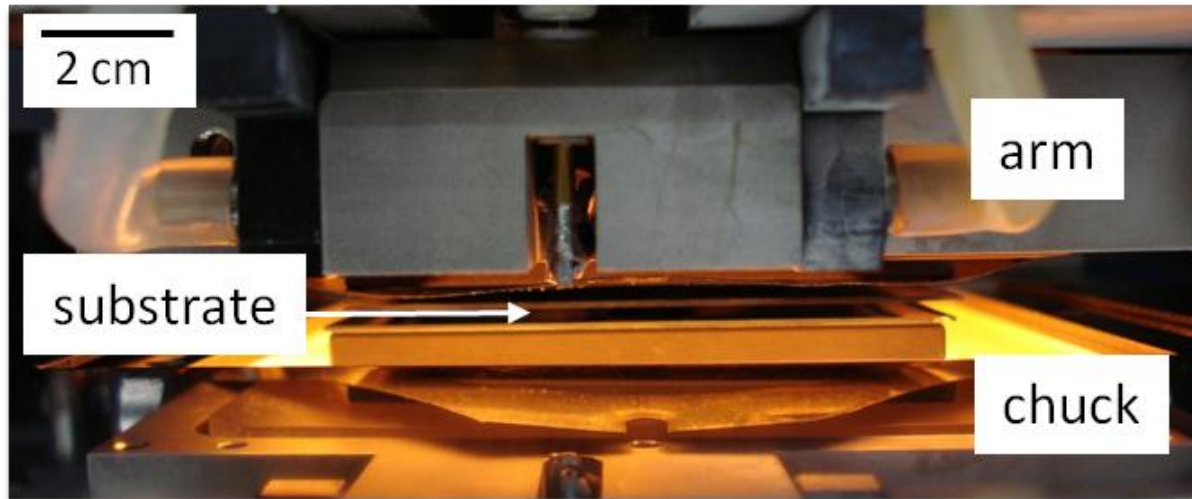
Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011



Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

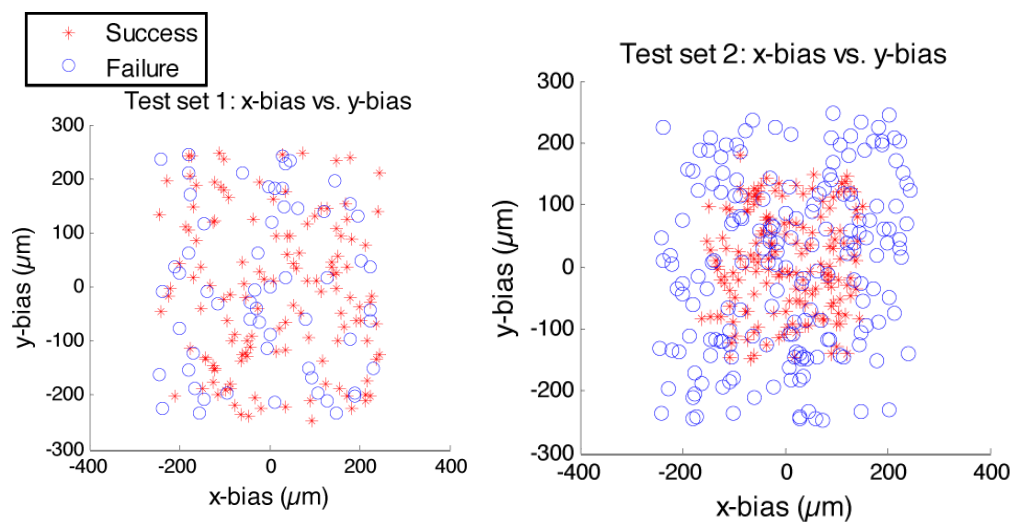
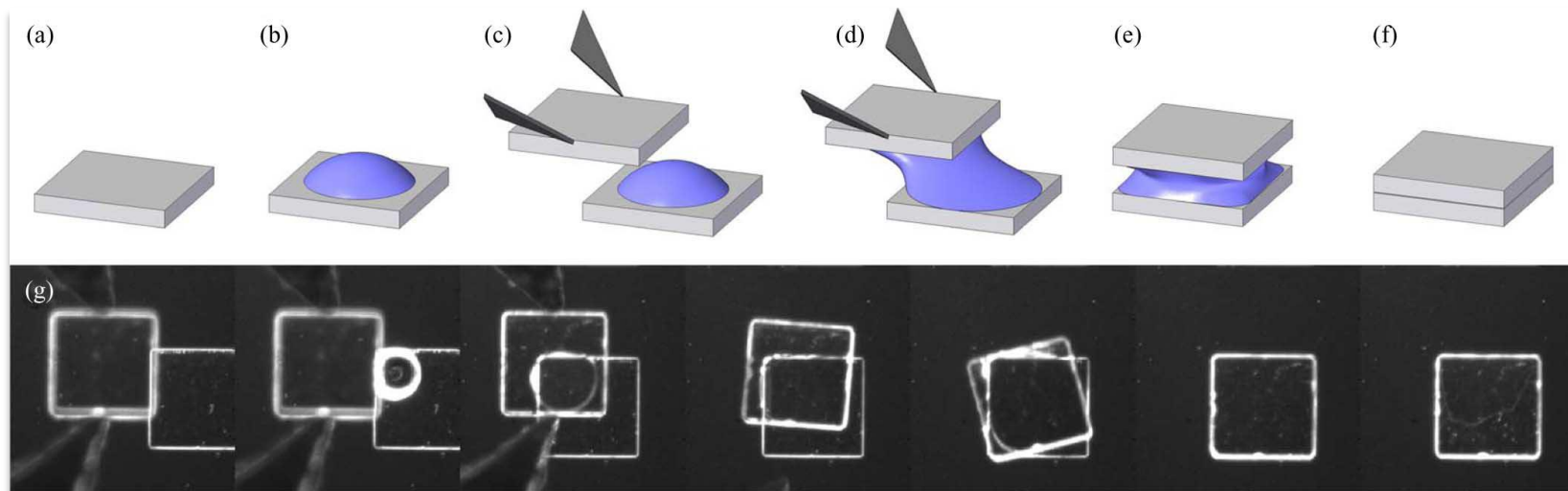
Failure Modes - 6

Thermocompression bonding

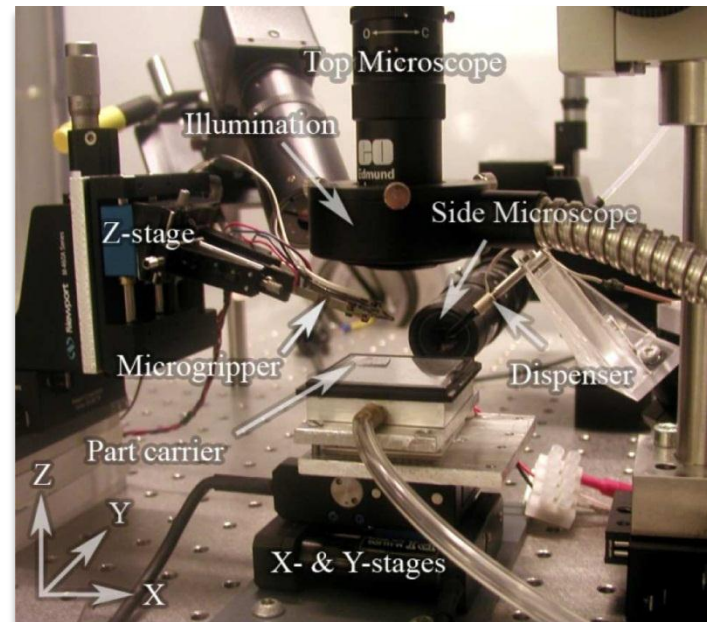


Mastrangeli et al., *IEEE T. Compon. Pack. T.*, 1(1), 133-149, 2011

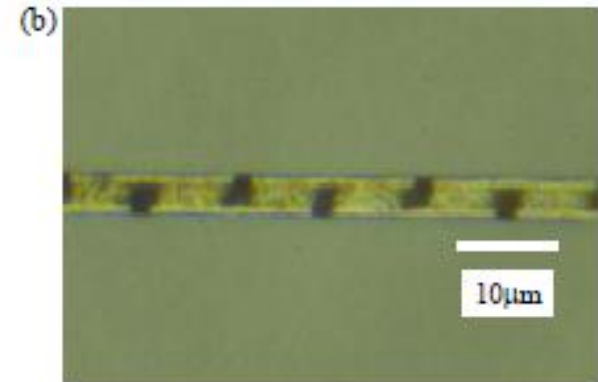
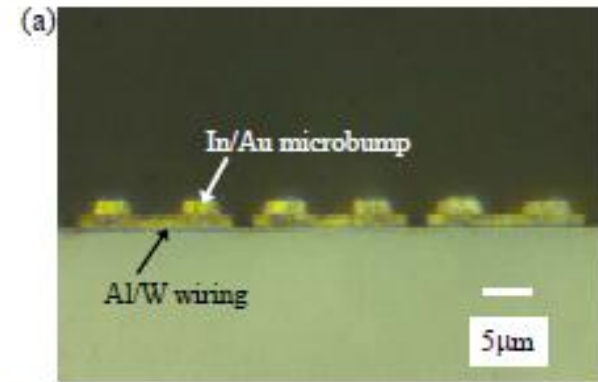
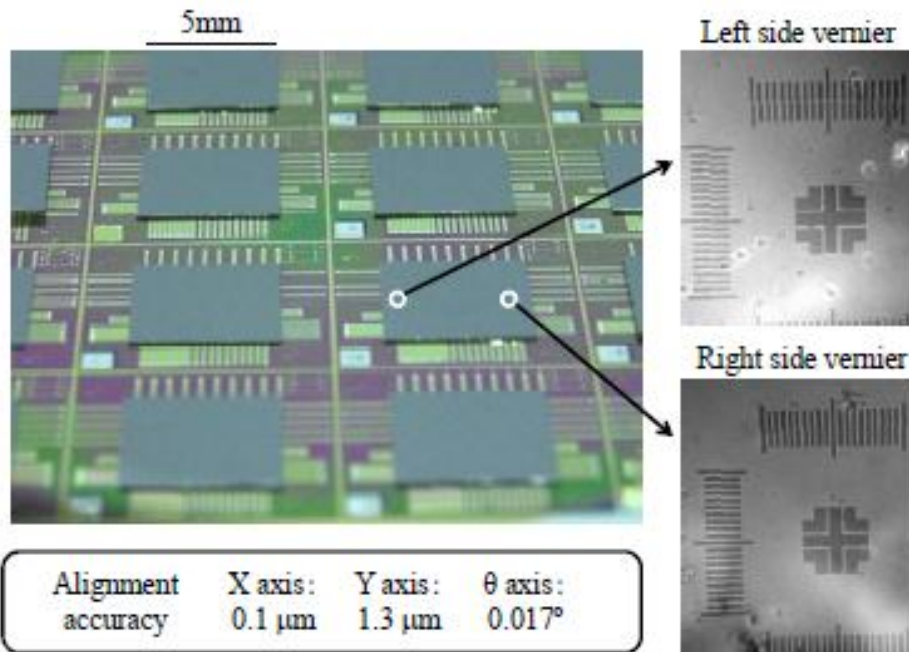
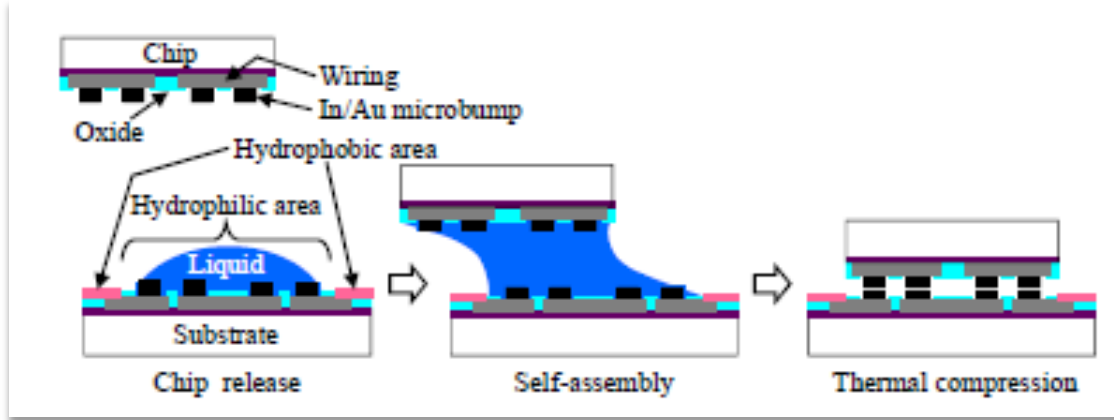
Hybrid Microhandling



Sariola et al., *IEEE T. Robot.* 26 (2010)



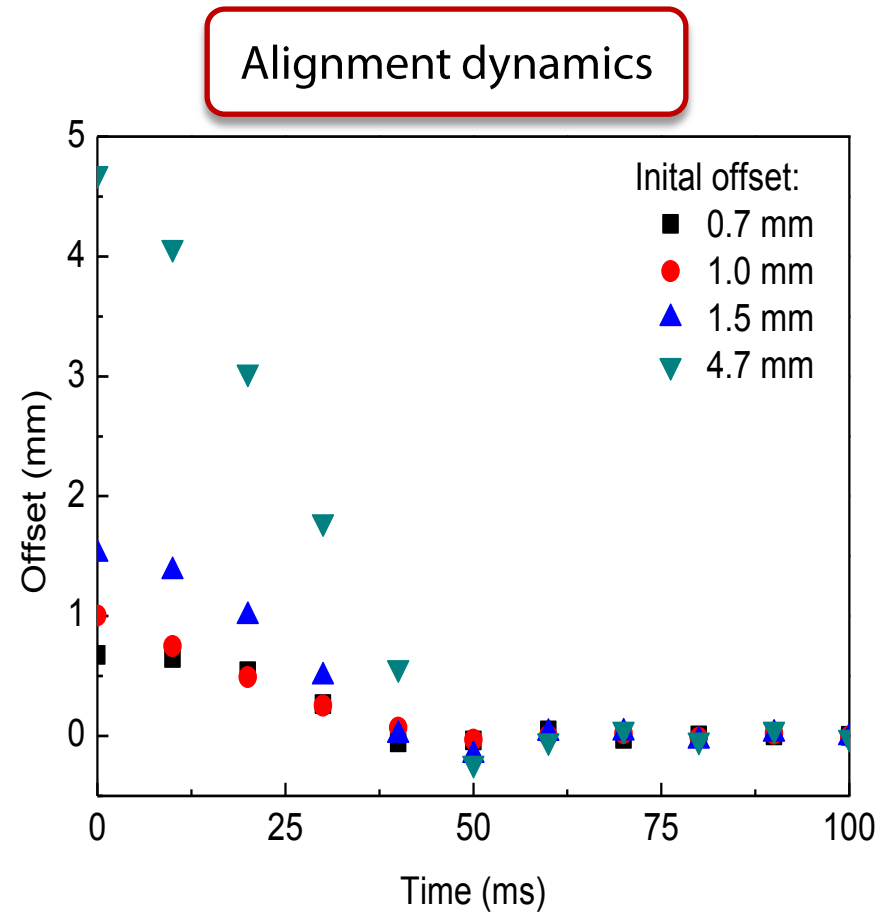
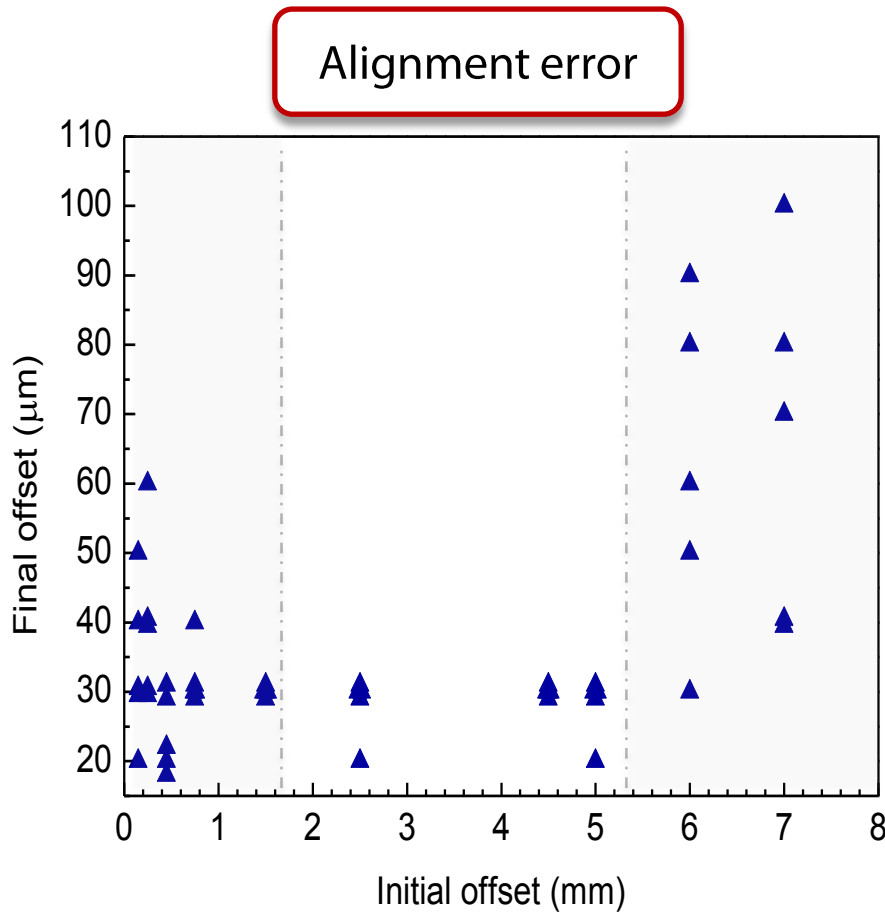
Capillary Self-Alignment of ICs



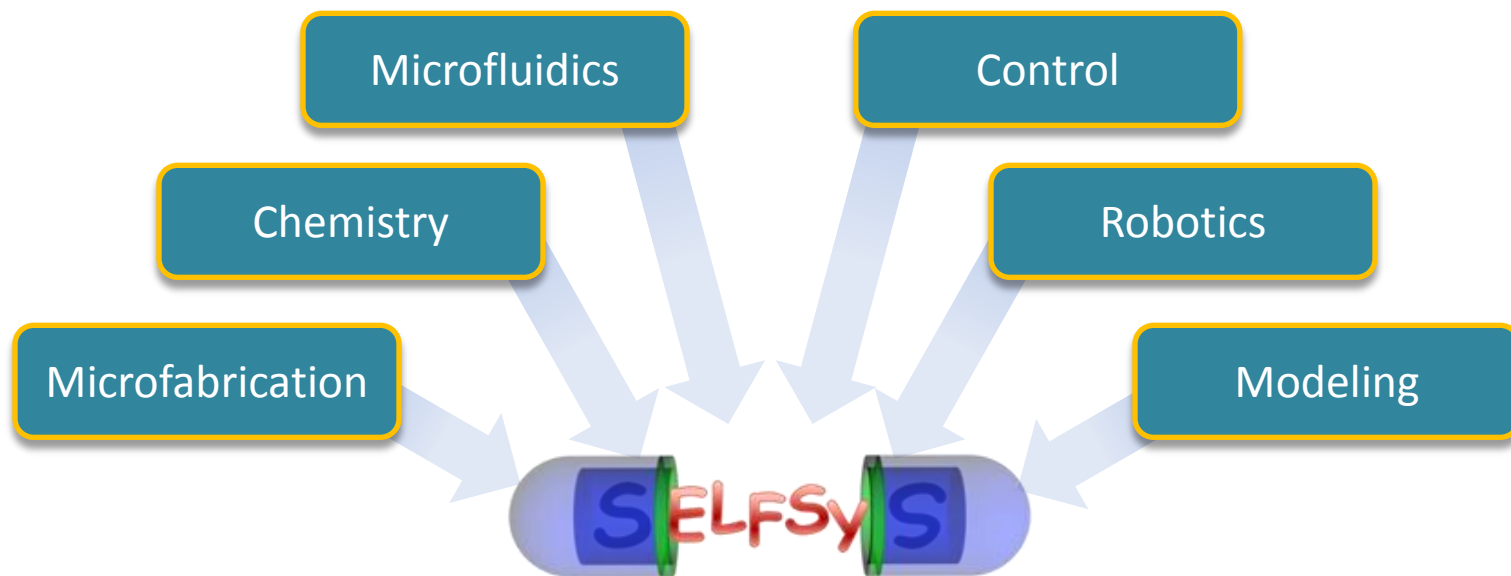
Size/pitch	5/10(μm)	10/20(μm)
Self-assembly	164 m Ω /bump	17.8 m Ω /bump
Conventional flip-chip assembly	208 m Ω /bump	15.2 m Ω /bump

Fukushima *et al.*, ECTC 2011

Capillary Self-Alignment of Foil Dies



Arutinov et al., submitted



Partners:

- EPFL/LMIS1 (*J. Brugger*) → Microfabrication
- EPFL/DISAL (*A. Martinoli*) → Modeling
- CSEM Alpnach (*H. Knapp*) → Microfluidics
- ETHZ/IRIS (*B. Nelson*) → Magnetic manipulation
- ETHZ/msystems (*C. Hierold*) → Magnetic particles
- ETHZ/LSST (*N. Spencer*) → Surface chemistry
- ETHZ/LTNT (*D. Poulikakos*) → Thermodynamics
- iCARE/RFID Center (*L. Sciboz*) → RFID

Sponsor



- Capillary self-alignment key to overcome the accuracy/throughput trade-off
- Know what to do and *not* to do for capillary SA
 - Surface conditioning, liquid choice and confinement, part feeding, assembly correction, bonding
- To improve:
 - Droplet control
 - Threaded sites
 - Jetting on recessed sites
 - Industrial acceptance
 - Capillary self-alignment works!

- **IMEC**
 - C. Van Hoof, W. Ruythooren, A. Witvrouw, E. Beyne, R. Agarwal, P. Limaye, A. Lamanna, K. Jans
- **MTM Dept. @ Katholieke Universiteit Leuven**
 - J.-P. Celis, B. Blanpain
- **EE Dept. @ University of Washington**
 - K. F. Böhringer, R. Baskaran, S. Abbasi, J. Hoo
- **BEAMS Dept. @ Université Libre de Bruxelles**
 - P. Lambert, J.-B. Valsamis
- **TNO**
 - G. Arutinov, E. C. P. Smits

Questions?

massimo.mastrangeli@epfl.ch

