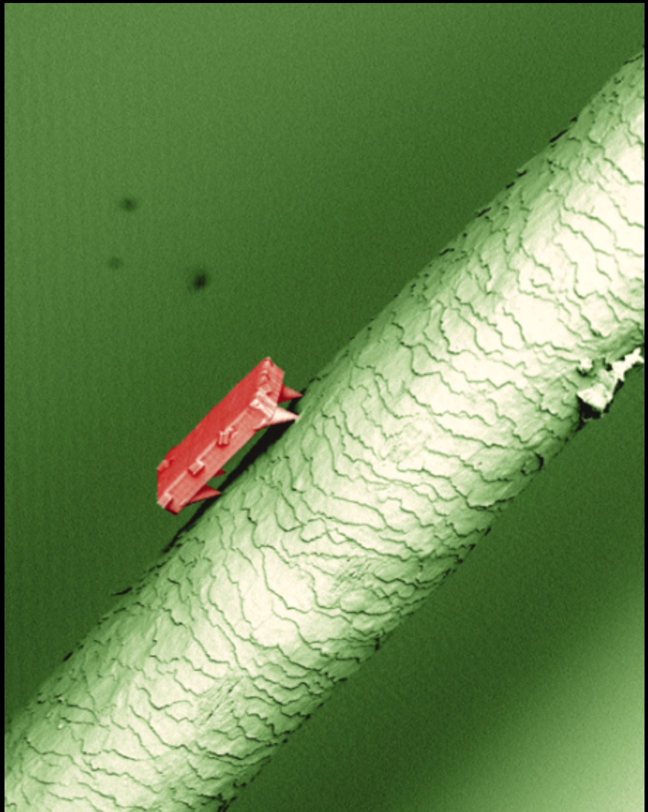
Photonics walking up a human hair

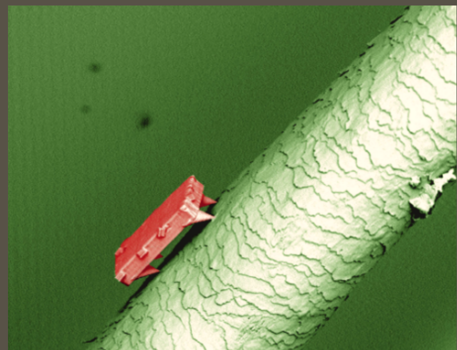
Diederik Wiersma

LENS (European Lab. Non-linear Spectroscopy)
INRIM (National Institute Metrology Research)
Univ. of Florence



Laws of physics – big and small

Diederik Wiersma



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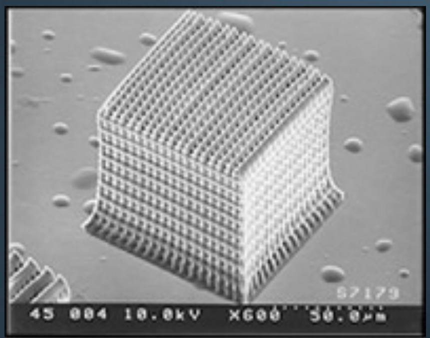
What do we want to do?

Photonic micro movement on length scale 1-100 μm



light

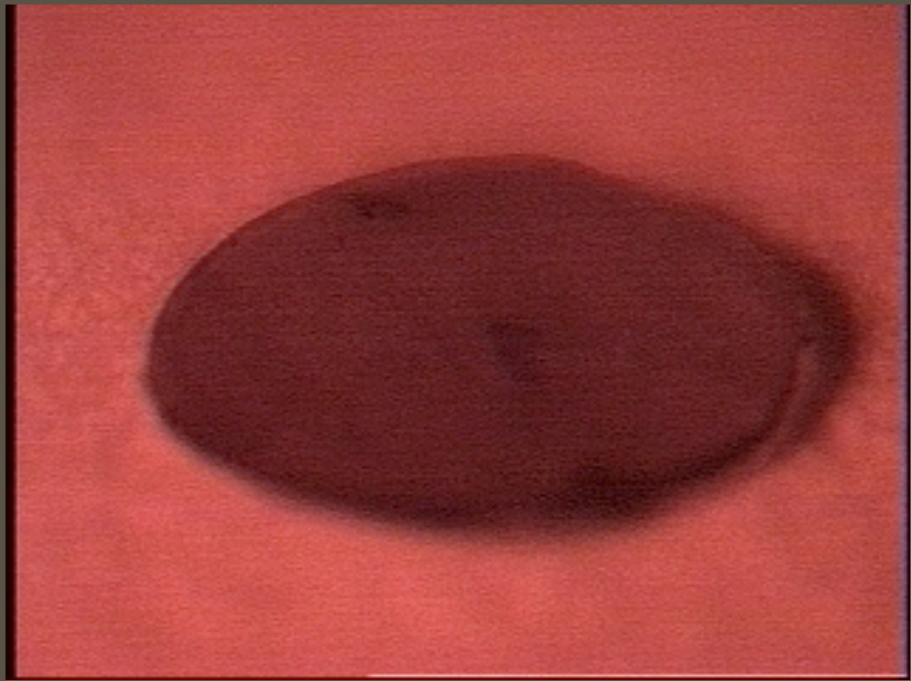
deformation / movement

The team


LENS
Nocentini
Nuzhdin
Ho
Zeng
Wasylczyk
Martella
Parmeggiani
Cerretti
Burresi
Wiersma

Light induced deformation

Dye-doped liquid crystal elastomer



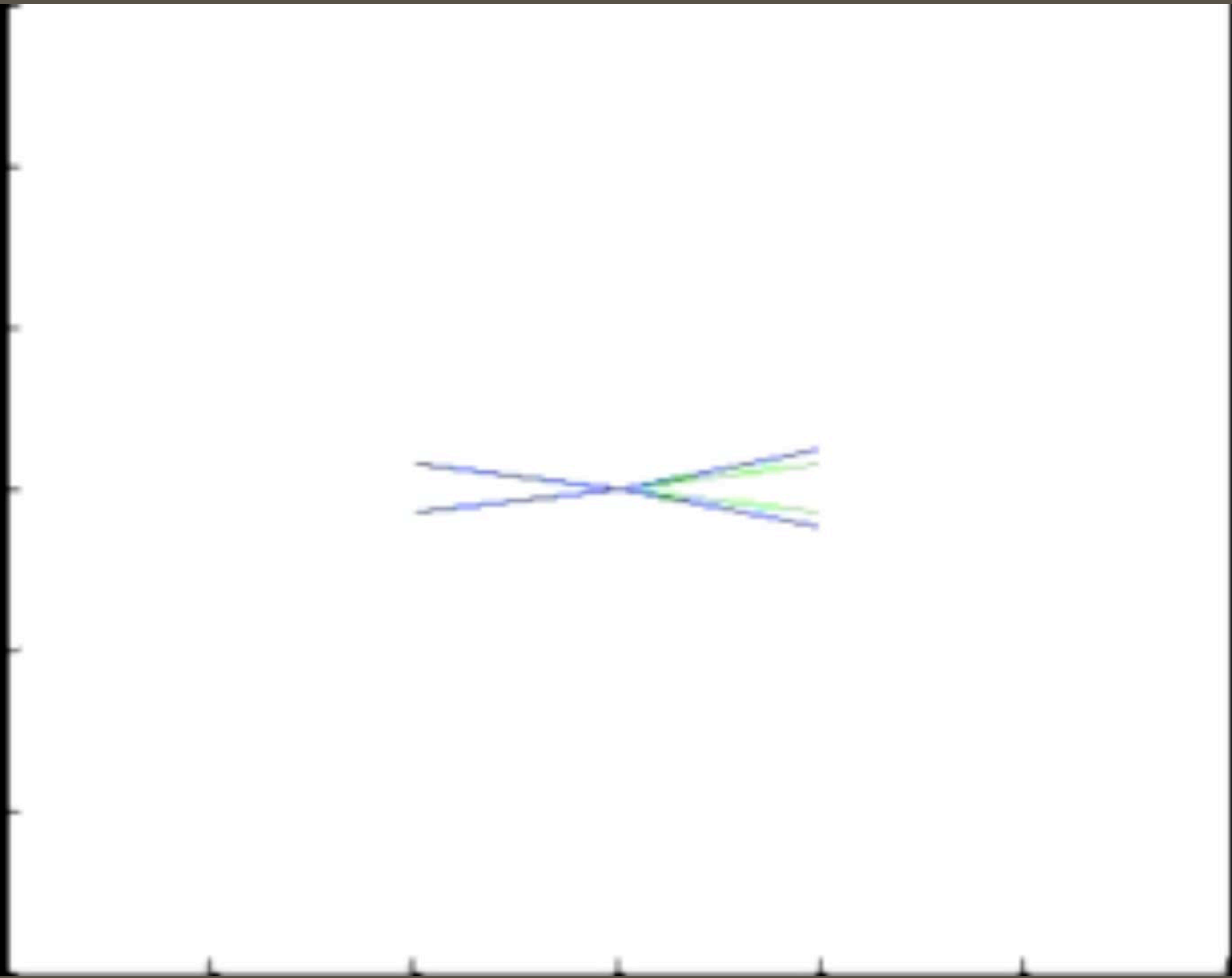
Peter Palffy-Muhoray, Kent State Univ.

Micrometer scale movement in fluids:

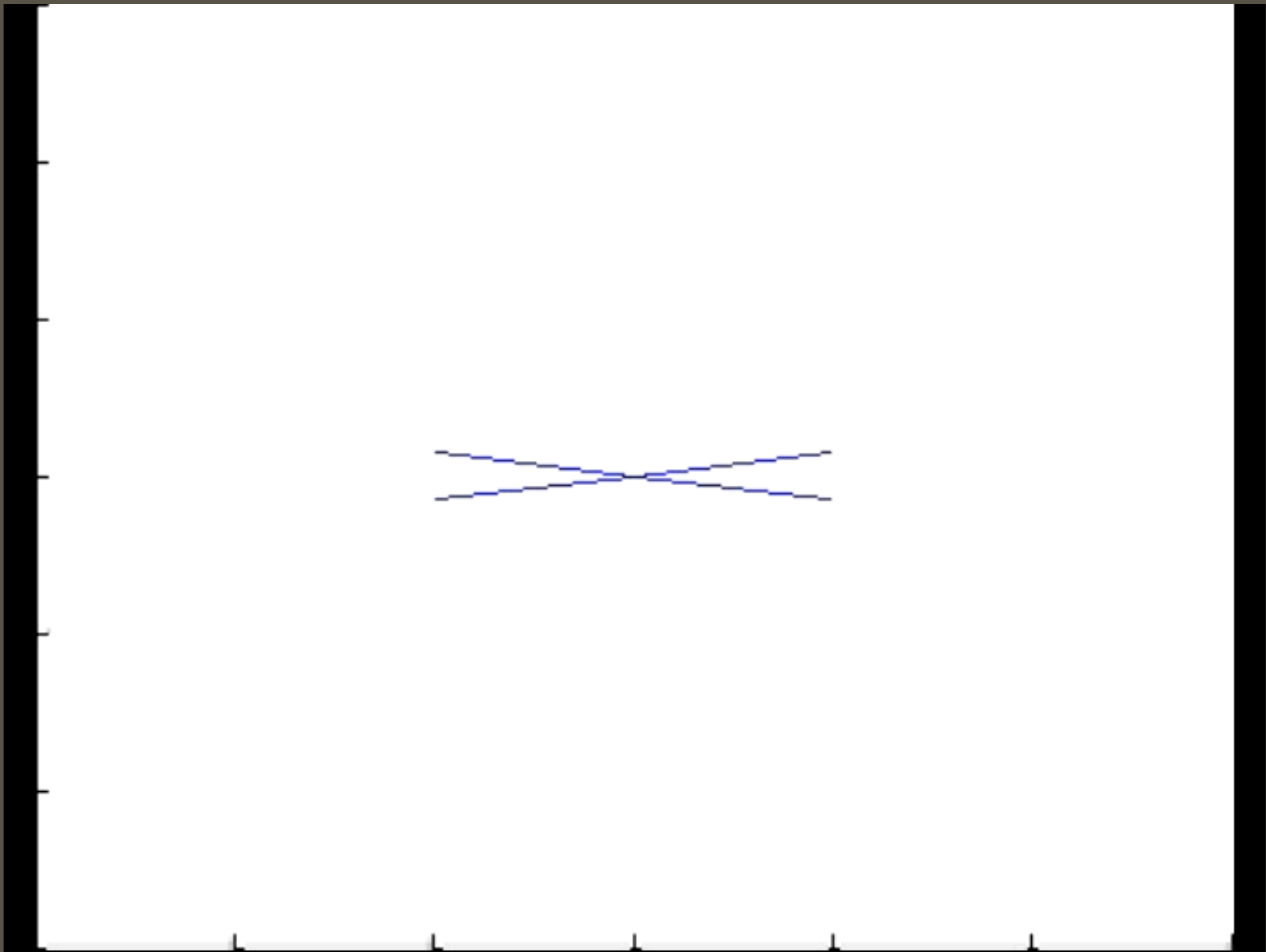
Low Reynold's number physics

$$\mathrm{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{\rho \mathbf{v} L}{\mu} = \frac{\mathbf{v} L}{\nu}$$

Trying to swim in honey

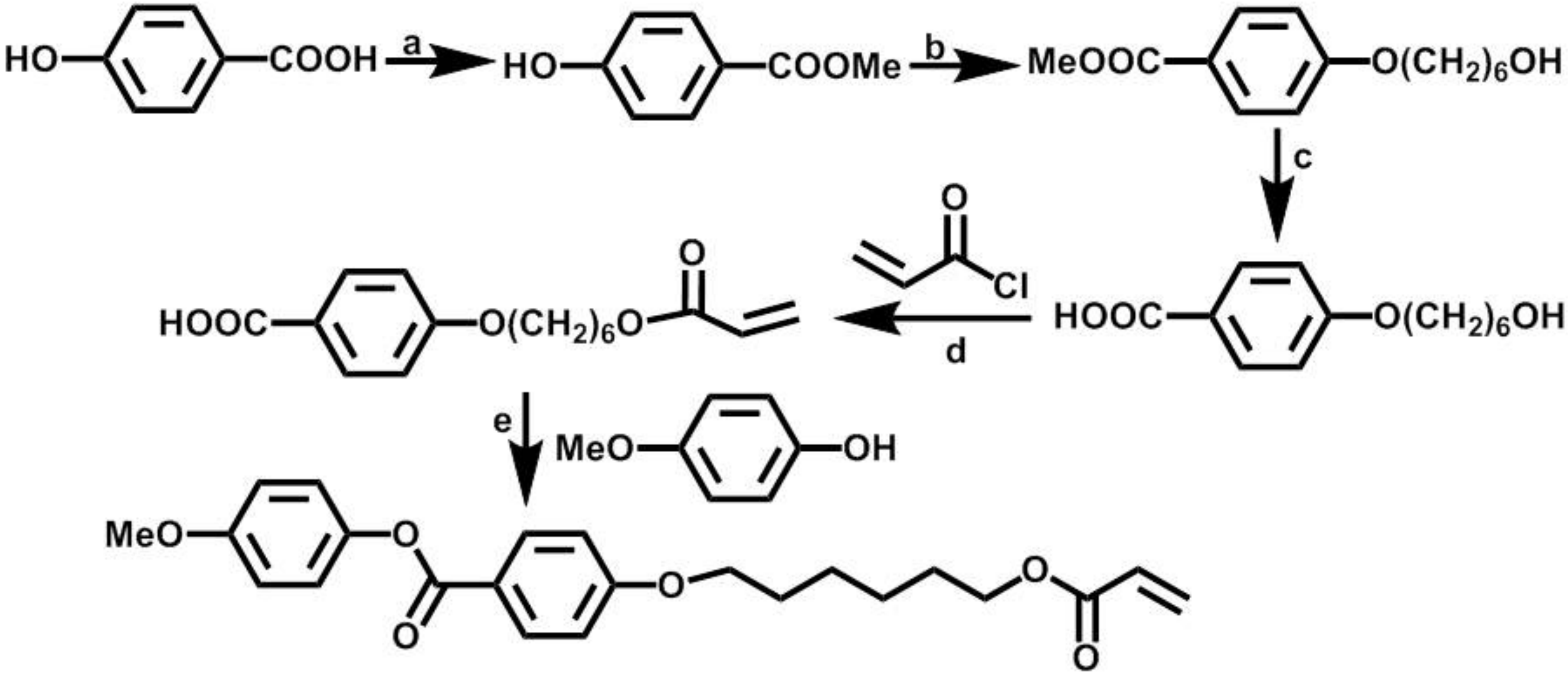


Non-reciprocal motion



Elastomers

New **mesogen** synthesized in order to change the polymerization direction and to improve the allignment

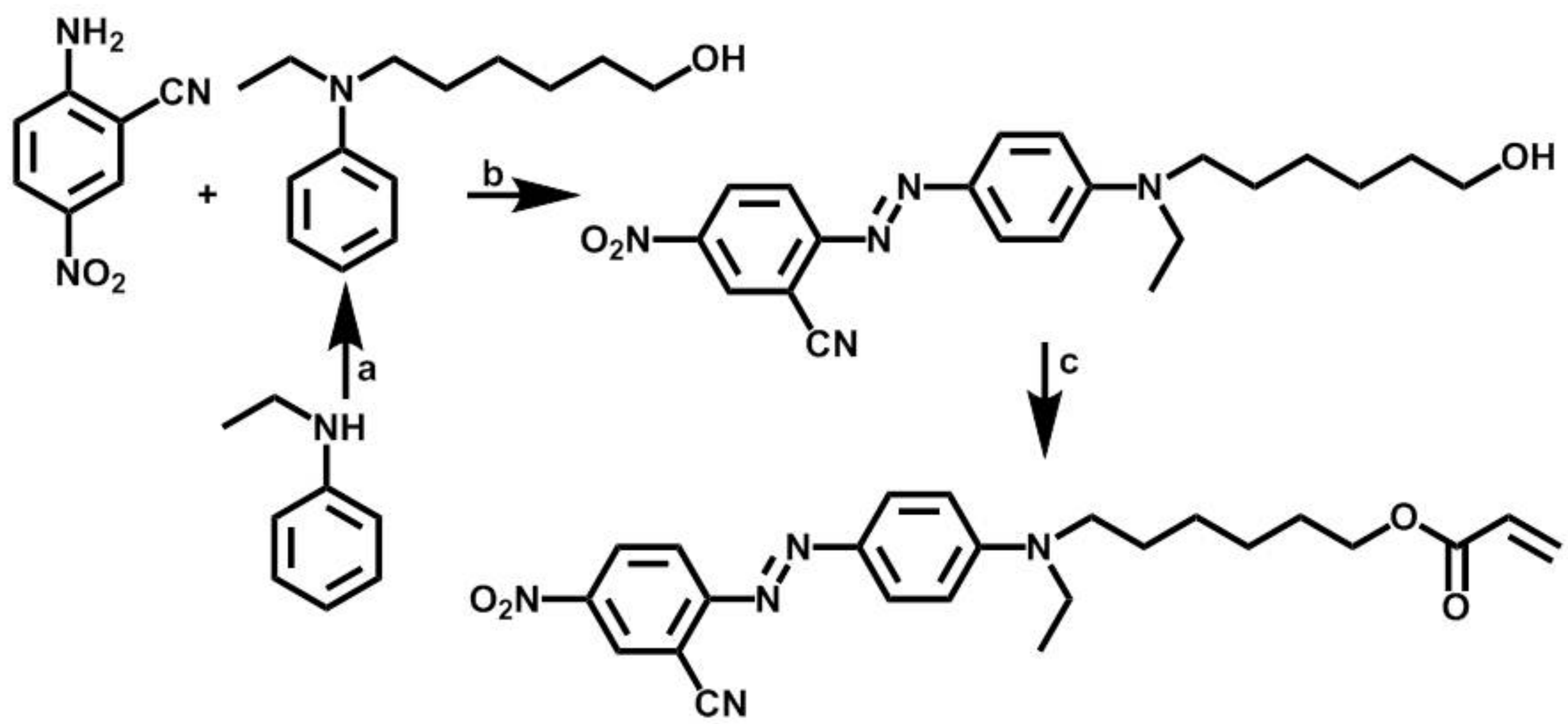


Reaction contidions:

a) MeOH, H_2SO_4, reflux, 18 h, 99%
b) Cl-hexanol, K_2CO_3, NaI, NMP, 85°C, 1 n, 100%
c) MeOH, KOH, 50°C, 13 h, 95%
d) NMP, rt, 3 h, 88%
e) DCC, DCM, 4-pyrrolidine pyridine, 1 n, 79%

J. D. Marty, M. Mauzac, C. Fournier, I. Rico-Lattes, A. Lattes, Liq. Cryst. 2002, 29, 529 – 536

New polymerizable dye with absorbtion at higher wavelenght



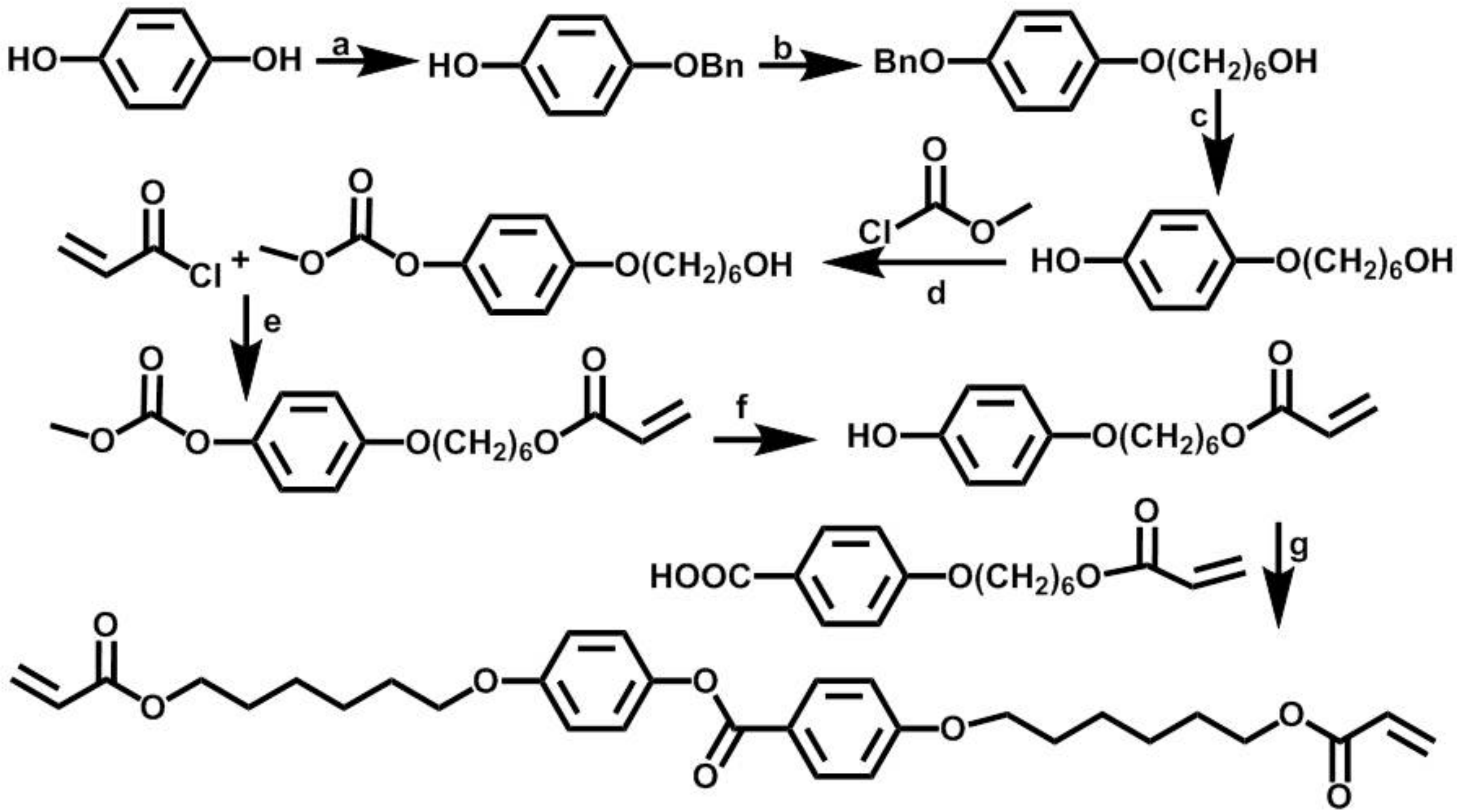
Reagents and conditions:

a) 6-chloro-1-hexanol, K_2CO_3, NaI, DMF, 80° C, 18 h, 70%;

b) $NaNO_2$, HCl, 0-5° C , then addition of the aniline in MeOH, 5° C, 2 h, 50%;

c) acryloyl chloride, Et_3N, CH_2Cl_2, rt, 2 h, 79%.

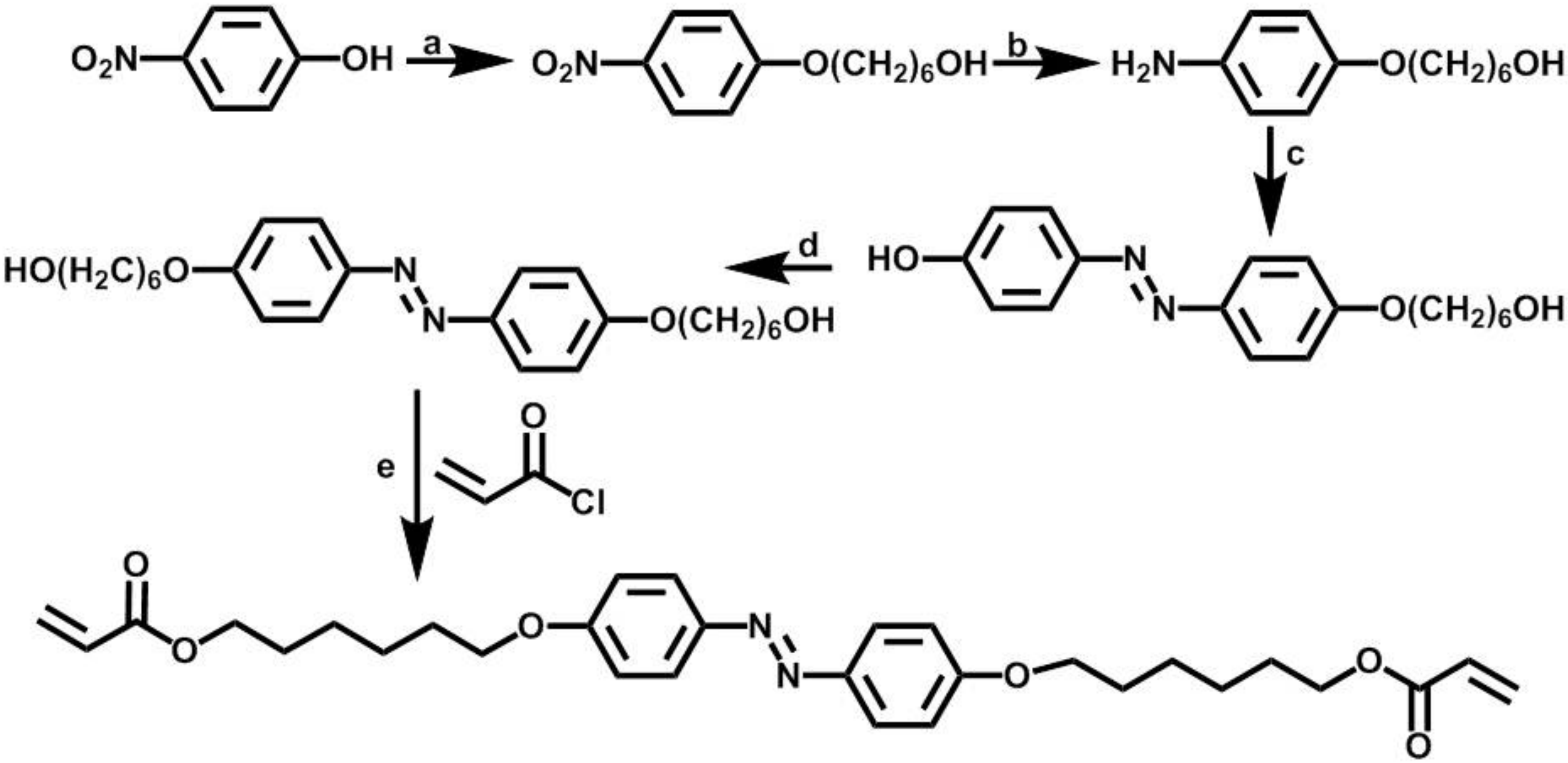
Liquid crystalline **Cross-linker**



Reaction contidions:

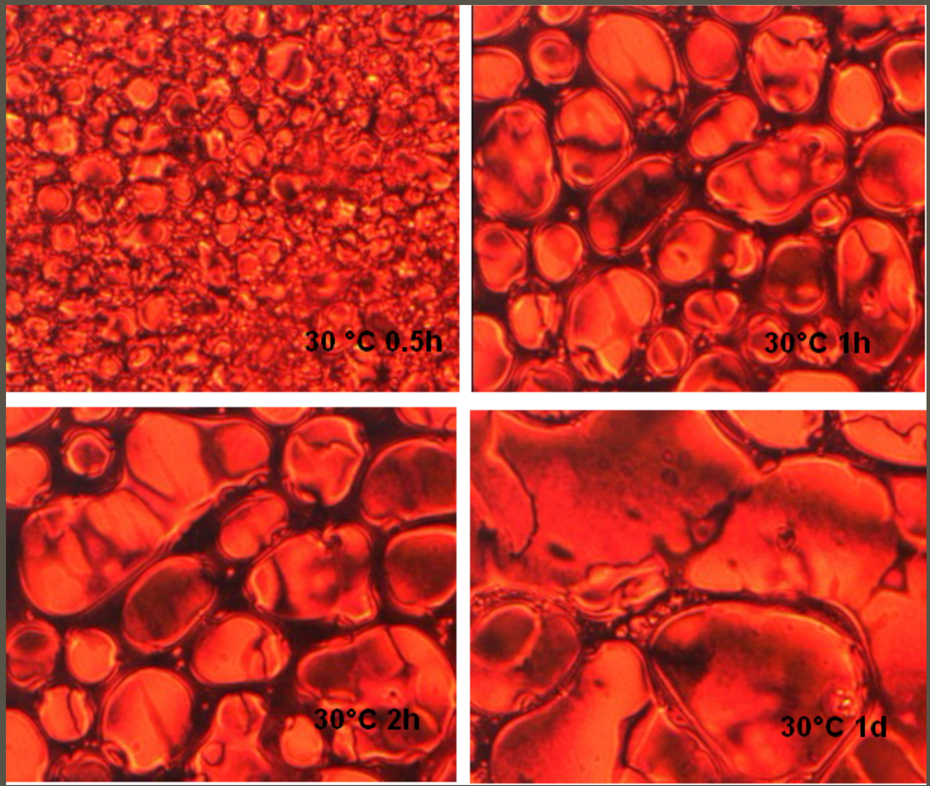
a) K_2CO_3, BnBr, acetone, reflux, 18 h, 51%; b)6-chloro-hexanol, K_2CO_3, DMF, KOH, 100°C, 18 h, 84%; c)Pd/C, H_2, DCM, rt, 18 h, 100%; d)NaOH, H_2O, rt, 4 h, 63%; e) NMP, 3 h, rt, 88%; f)EtOH:NH_3 33%, 6:1, 2 h, rt, 83%; g) DCC, DCM, 4-pyrrolidine pyridine, rt, 1 n, 39%

Dye containing cross-linker



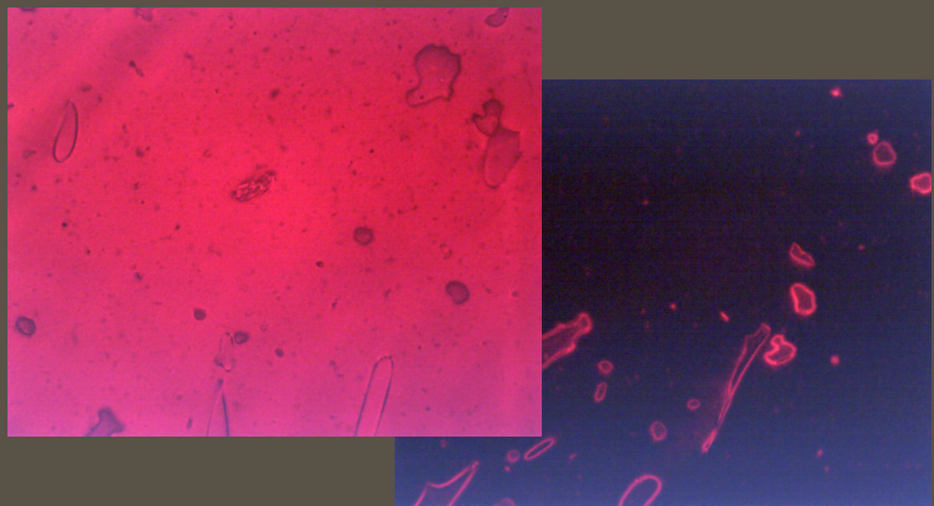
Reaction contidions:

a) 6-chloro-hexanol, K_2CO_3, DMF, 100°C, 18 h, 83%; b) Pd/C, H_2, MeOH, rt, 18 h, 99%; c) 1. HCl, H_2O, 2. $NaNO_2$, H_2O, 0°C, 3. PhOH, NaOH, 30 min, 0°C, 85%; d) 6-chloro-hexanol, K_2CO_3, DMF, 100°C, 18 h, 91%; e) DCC, DCM, 4-pyrrolidine pyridine, rt, 1 n, 67%.



Pure CPL 9 on rubbed substrate

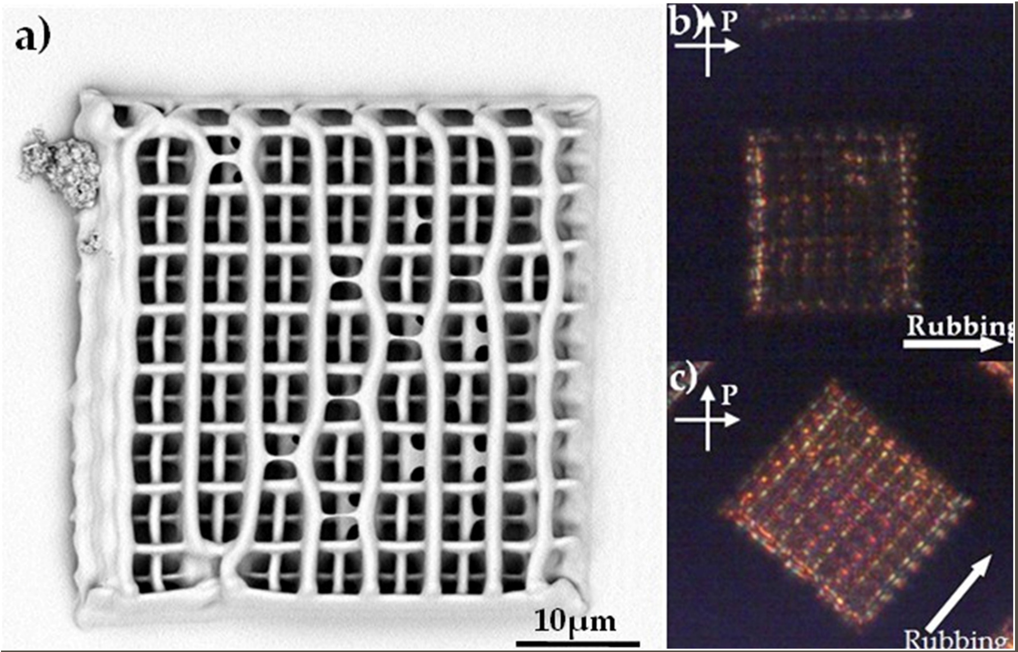
~5min to obtain monodomain

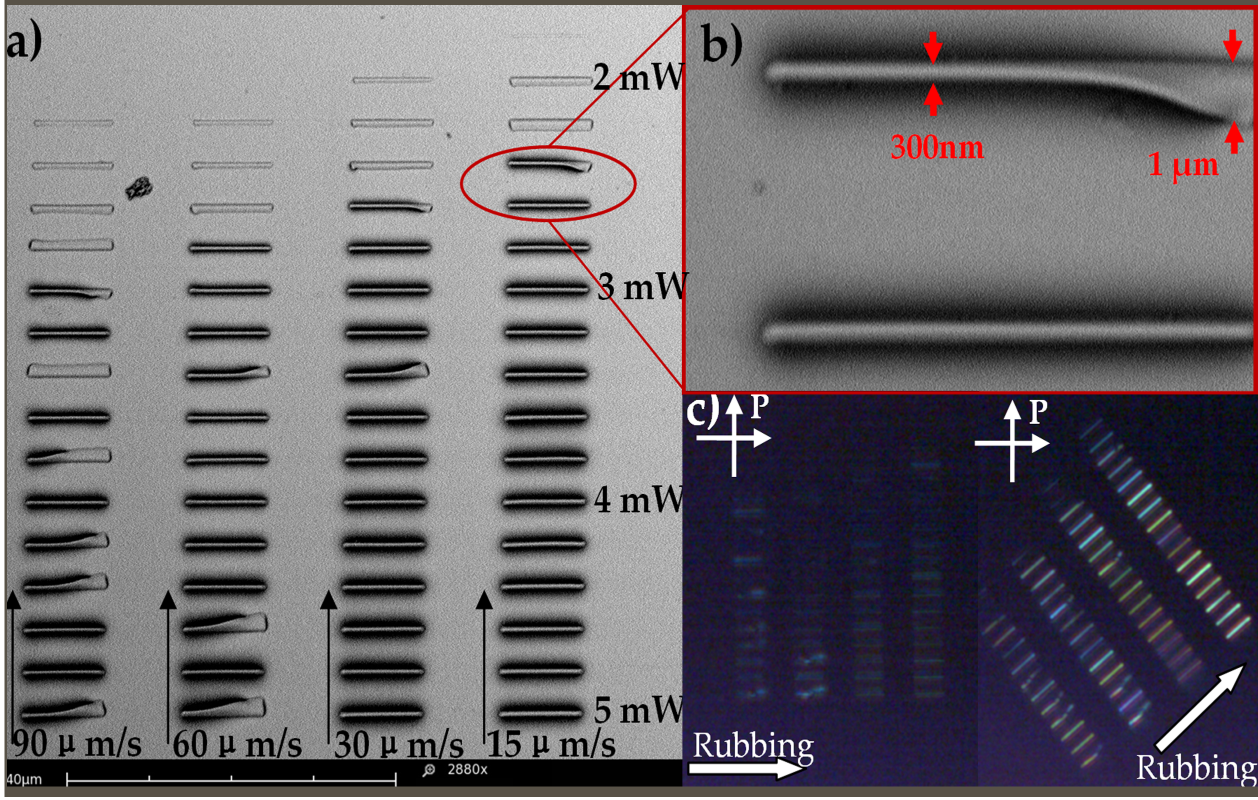


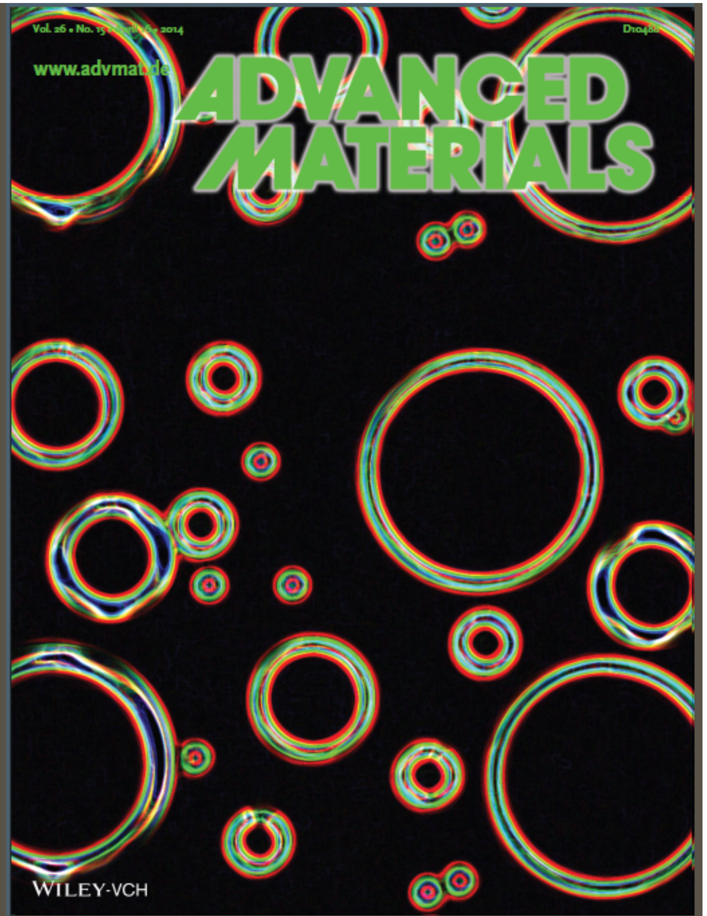
Left 45 degree to cross polarizer
Right 90 degree to cross polarizer

Micro structuring

Direct laser writing





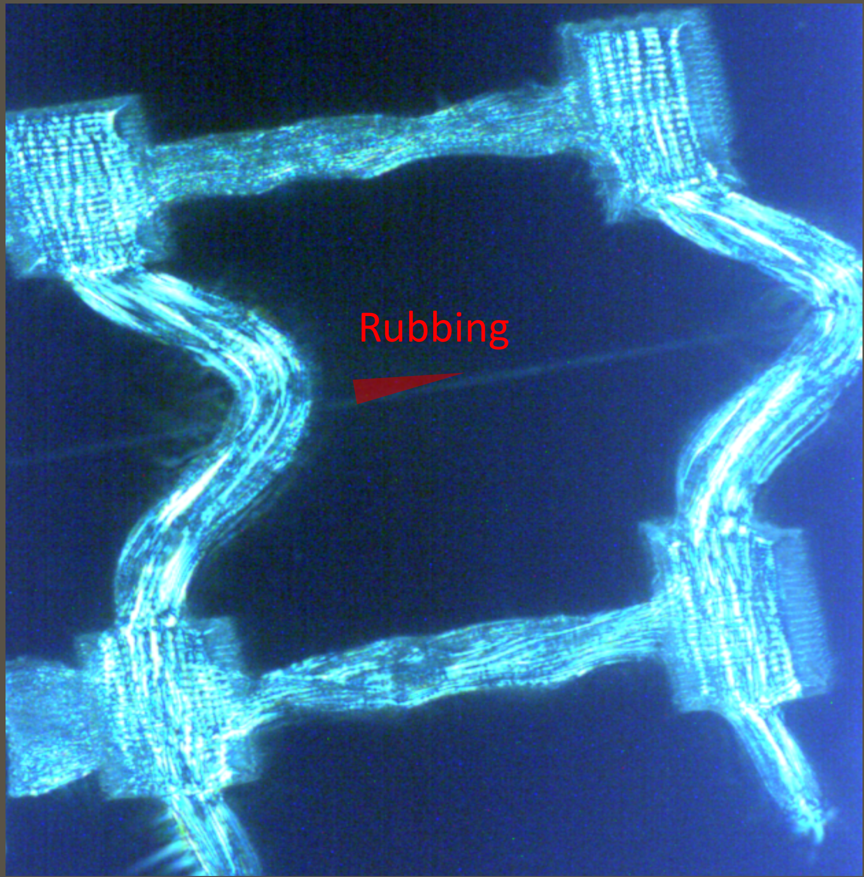


Adv. Mater. 26, 2319 (2014).

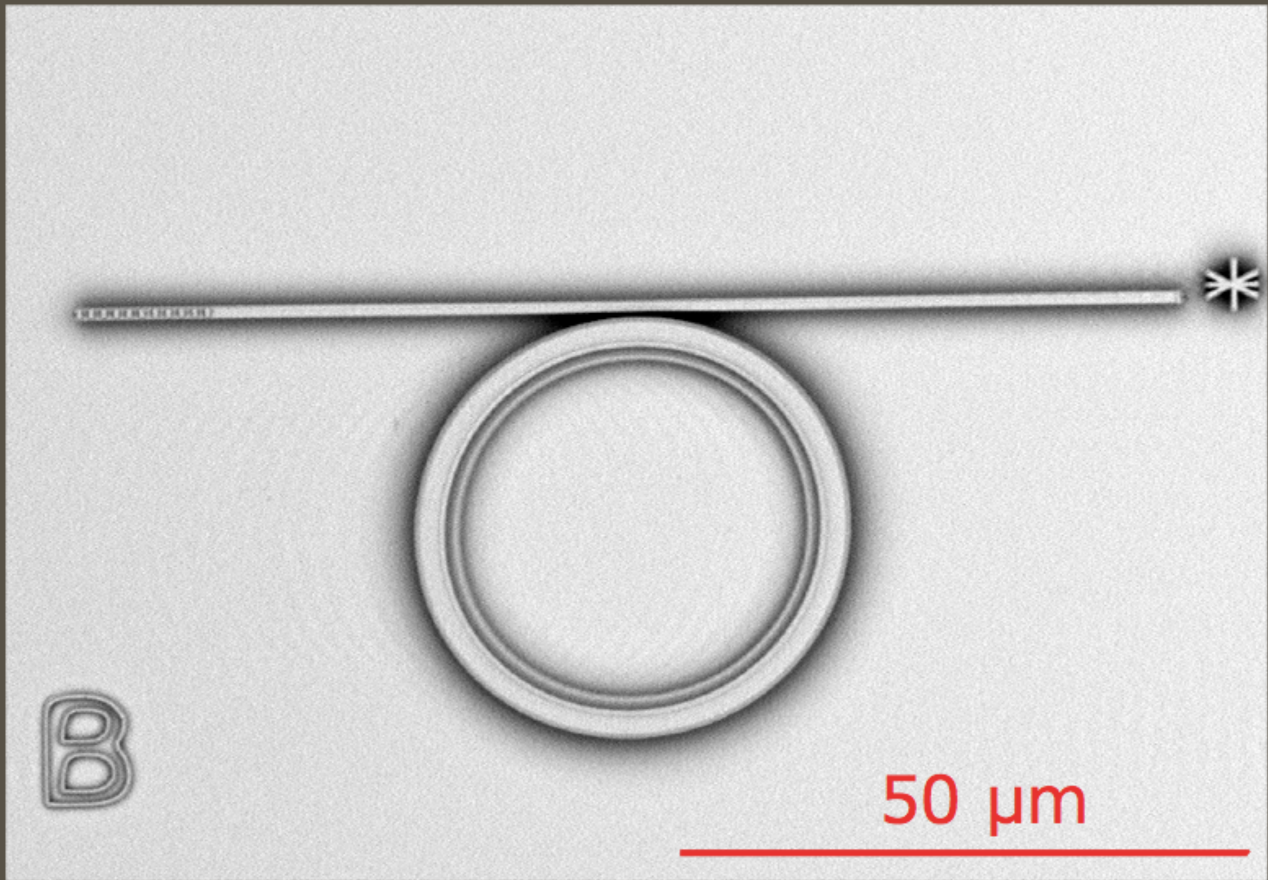
Preliminary results

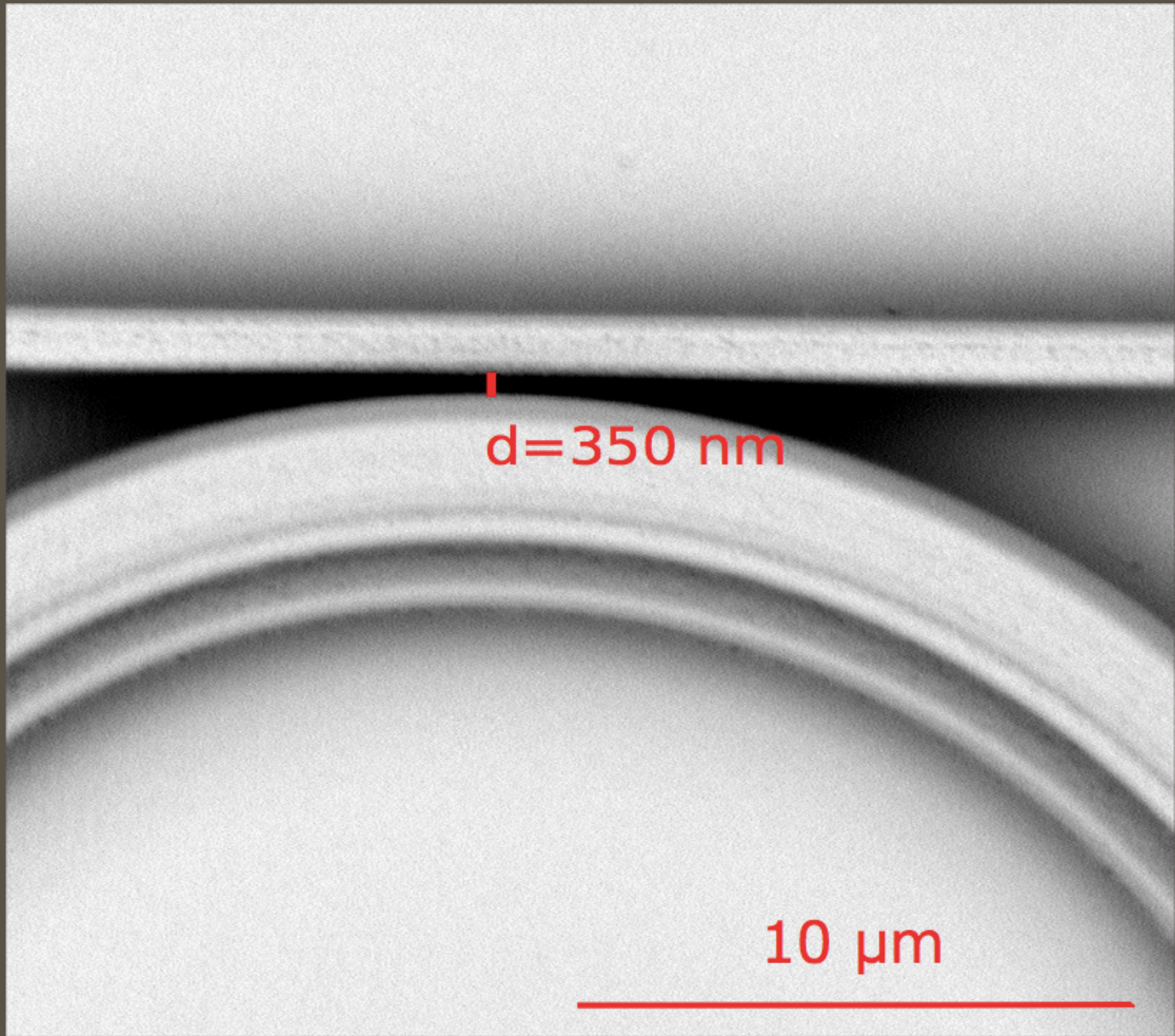
- All polymer combined optical components
- Controlled alignment of liquid crystals
- Actuators, arms, legs, and wrists....

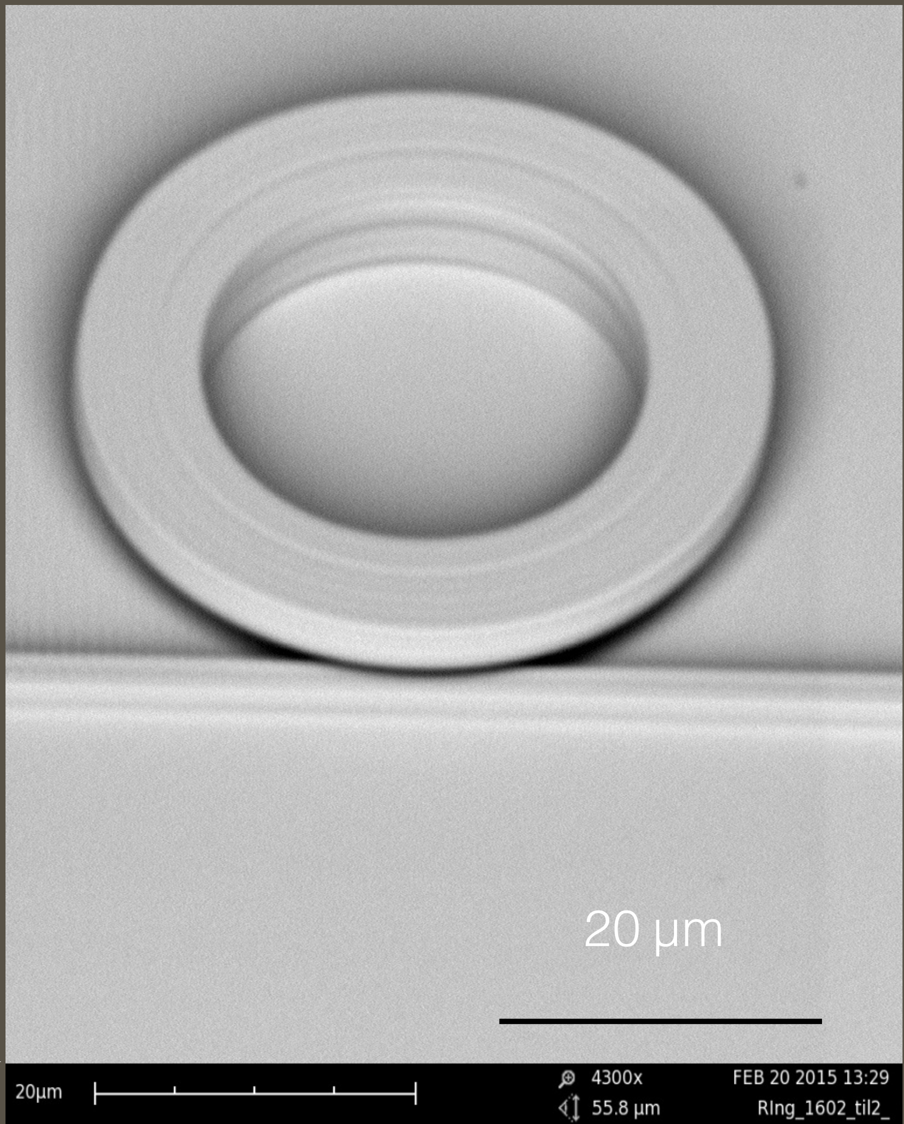
Many things go wrong

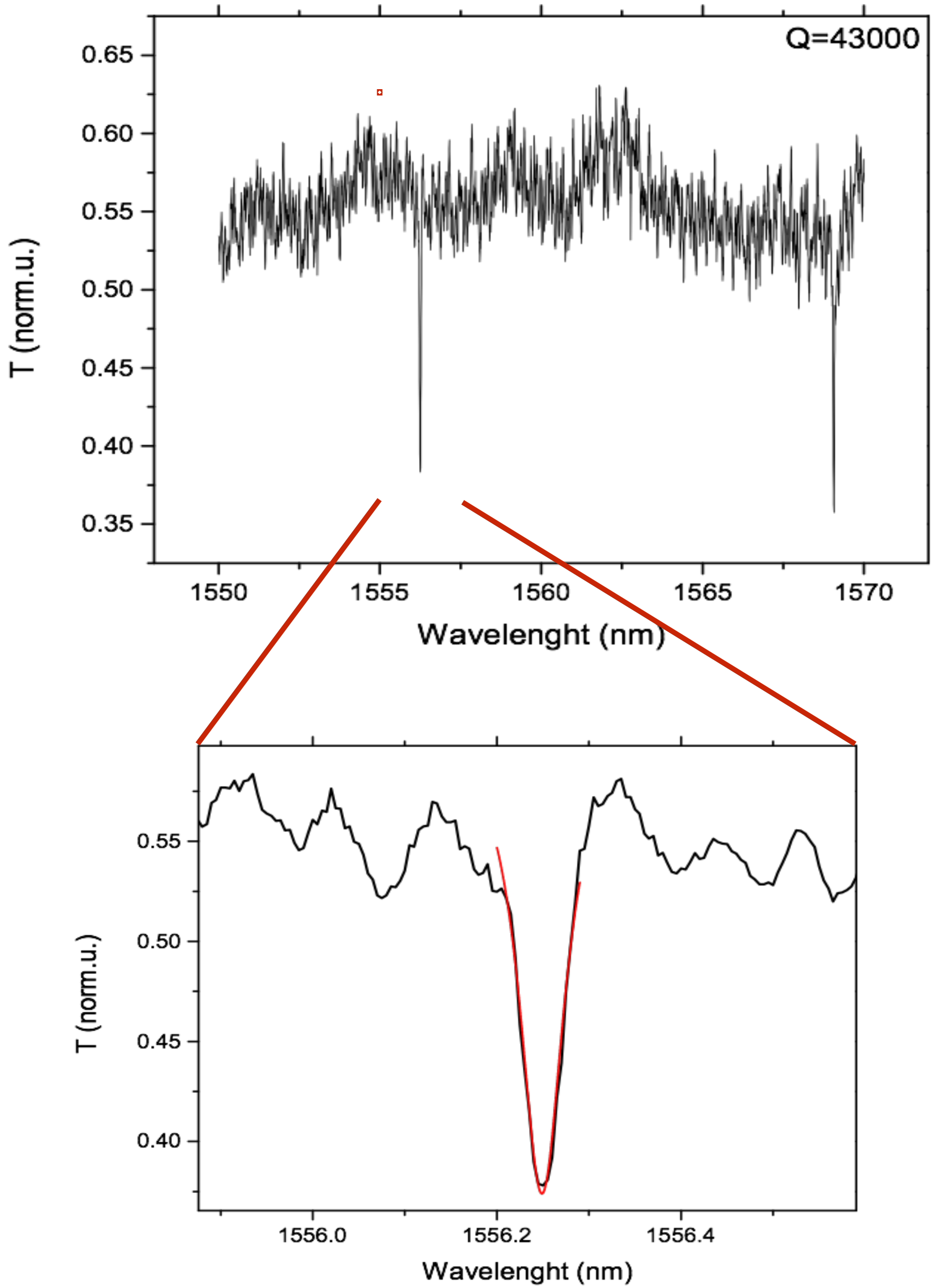


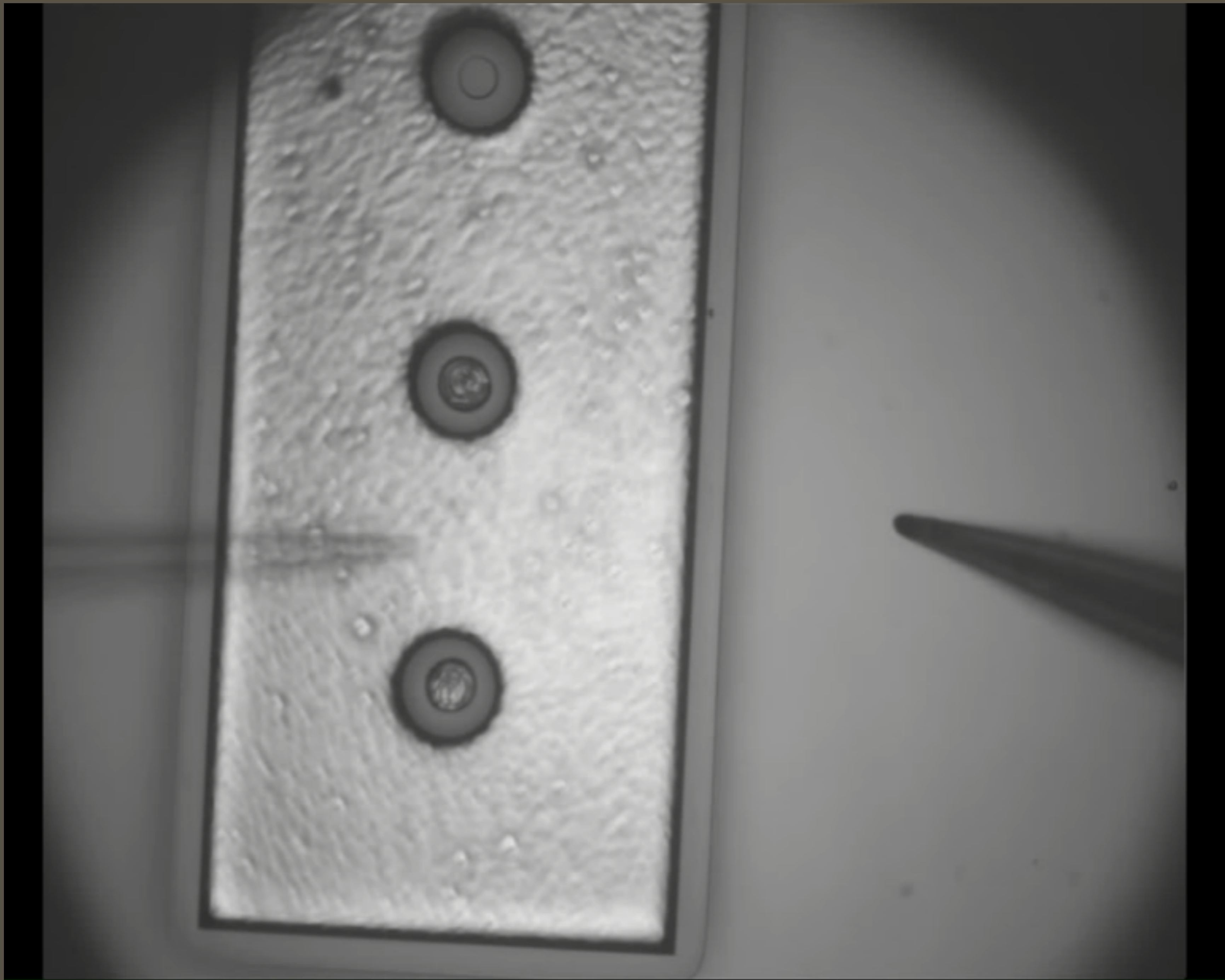
But some things go right...



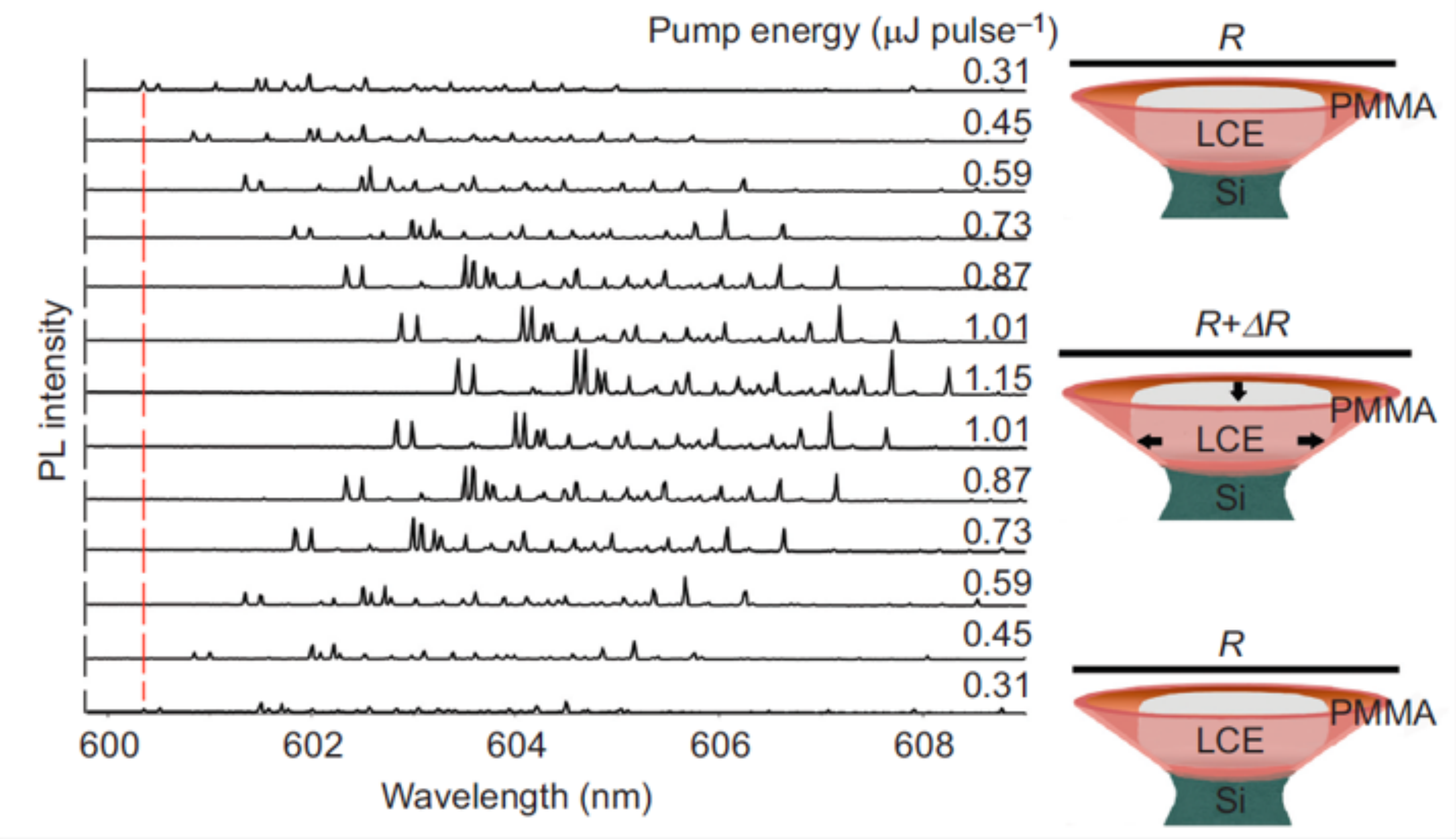

d=350 nm
10 µm


20 µm
20µm
4300x
55.8 µm
FEB 20 2015 13:29
RIng_1602_til2_


Q=43000
0.65
0.60
0.55
0.50
0.45
0.40
0.35
T (norm.u.)
1550
1555
1560
1565
1570
Wavelenght (nm)
0.55
0.50
0.45
0.40
T (norm.u.)
1556.0
1556.2
1556.4
Wavelenght (nm)



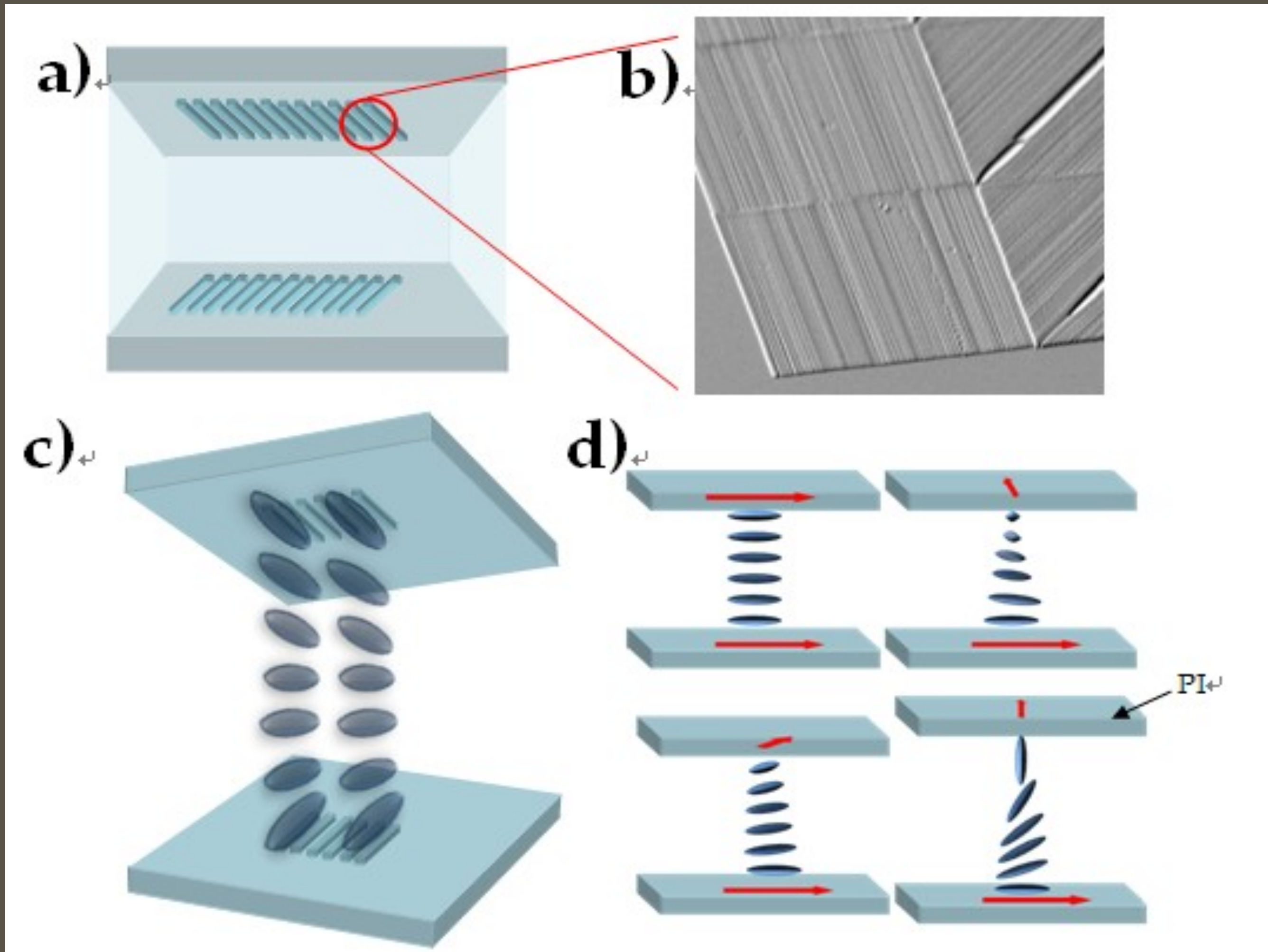
Optically Controlled Elastic Micro-laser

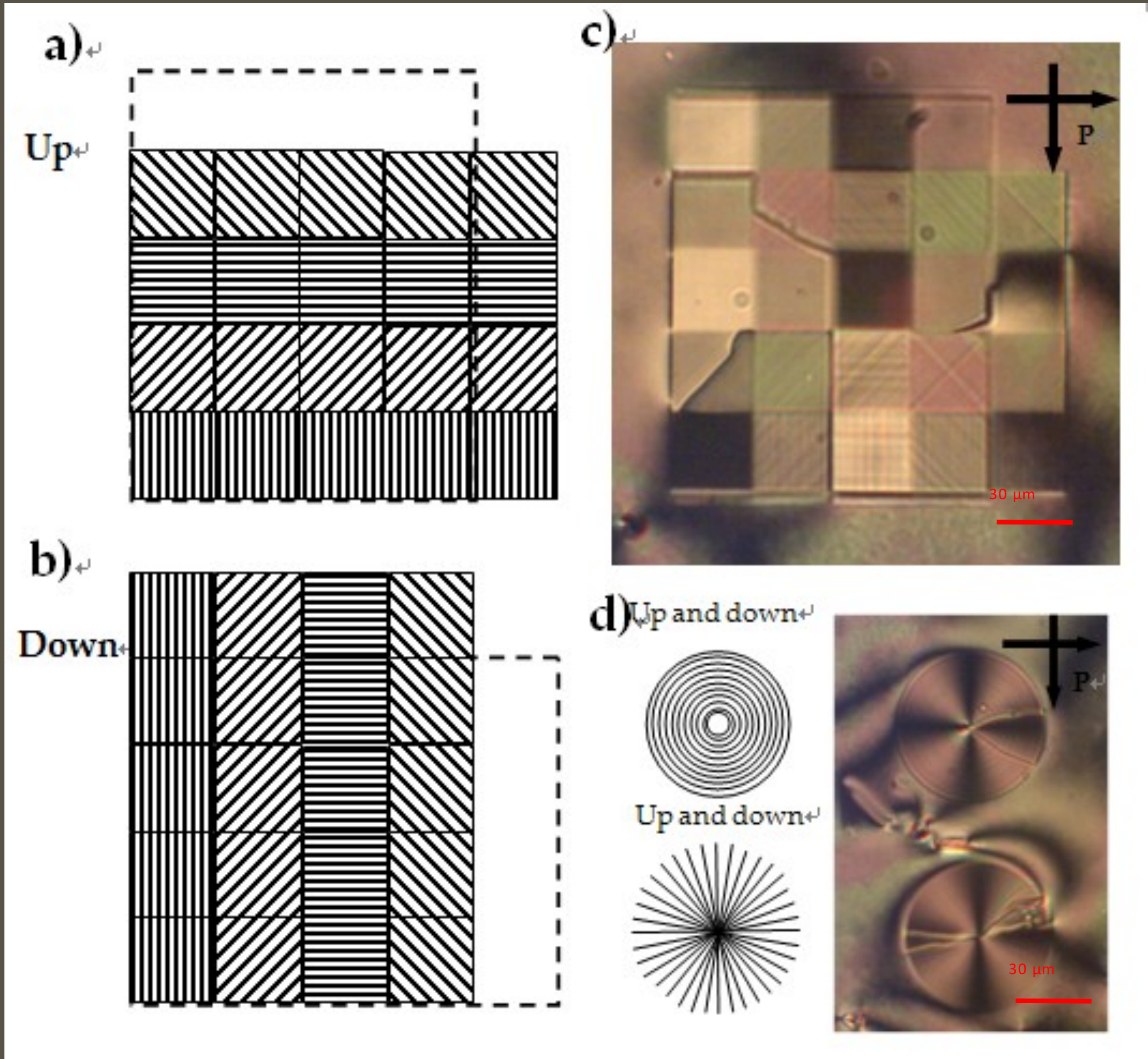


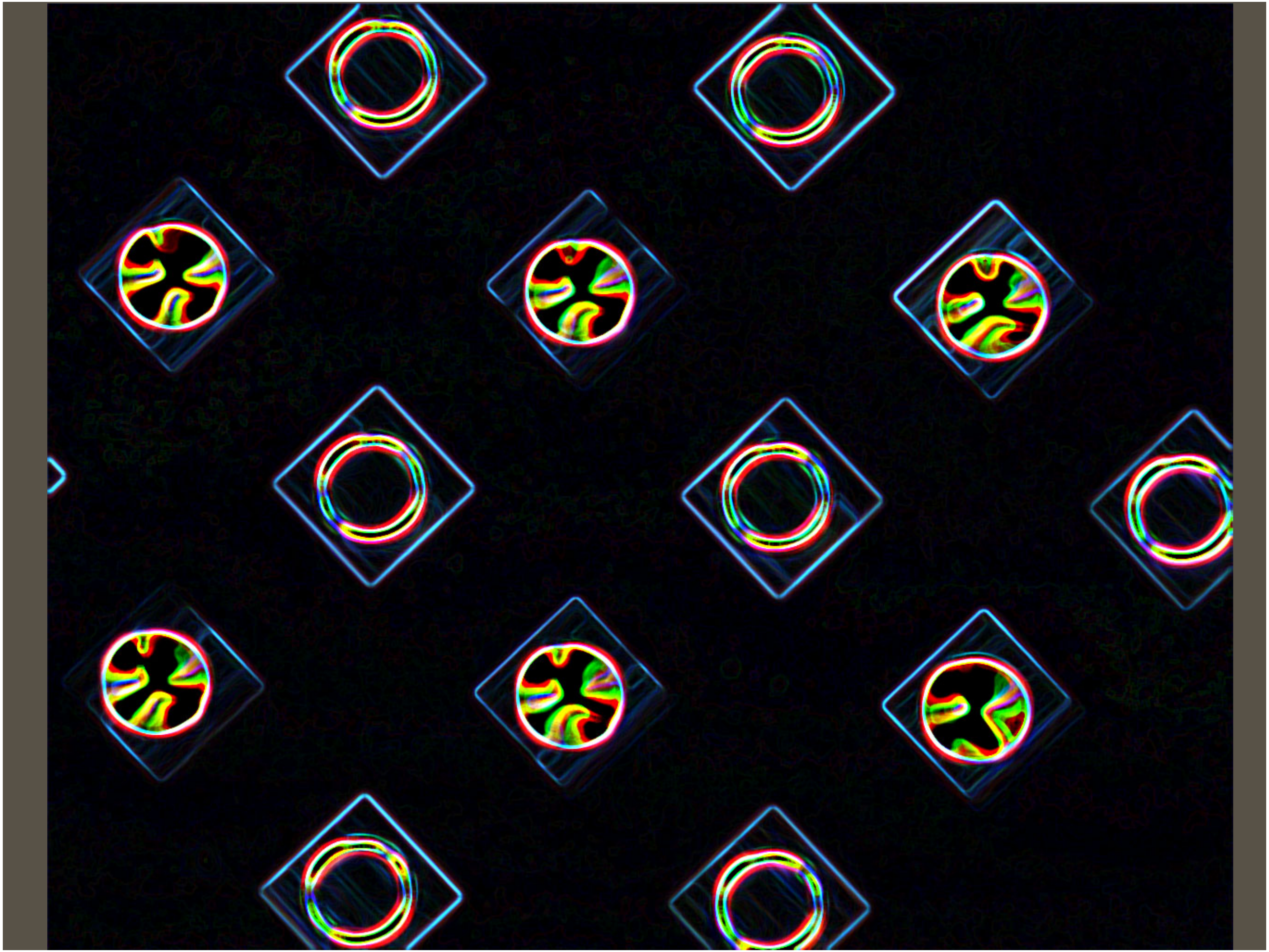
Light: Science & Applications 4, e282 (2015)

Elements for robotics

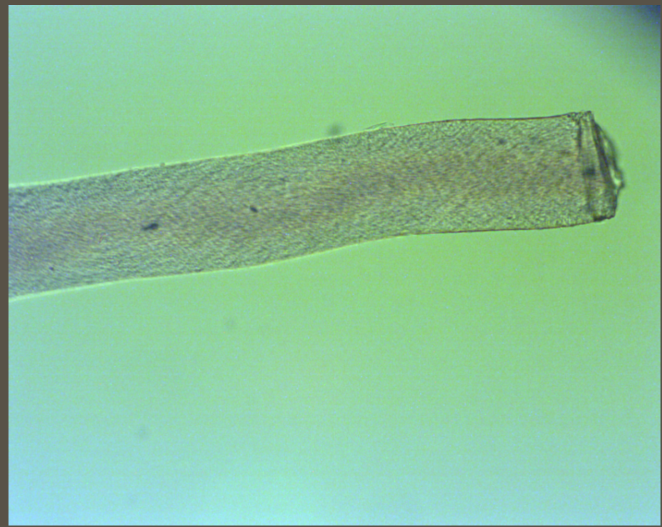
Engineering the alignment of the elastomer




a)
Up
b)
Down
c)
P
30 µm
d) Up and down
Up and down
P
30 µm

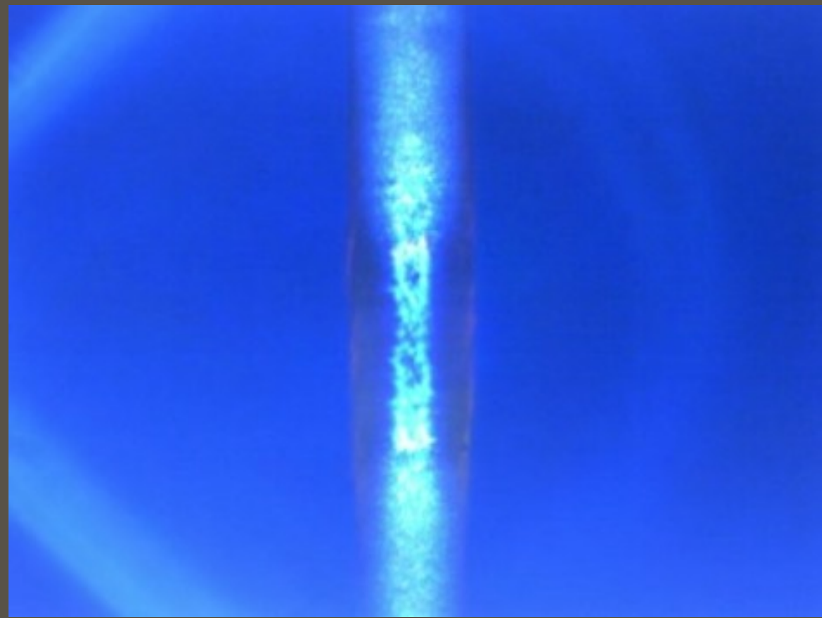


Linear actuator and oscillator



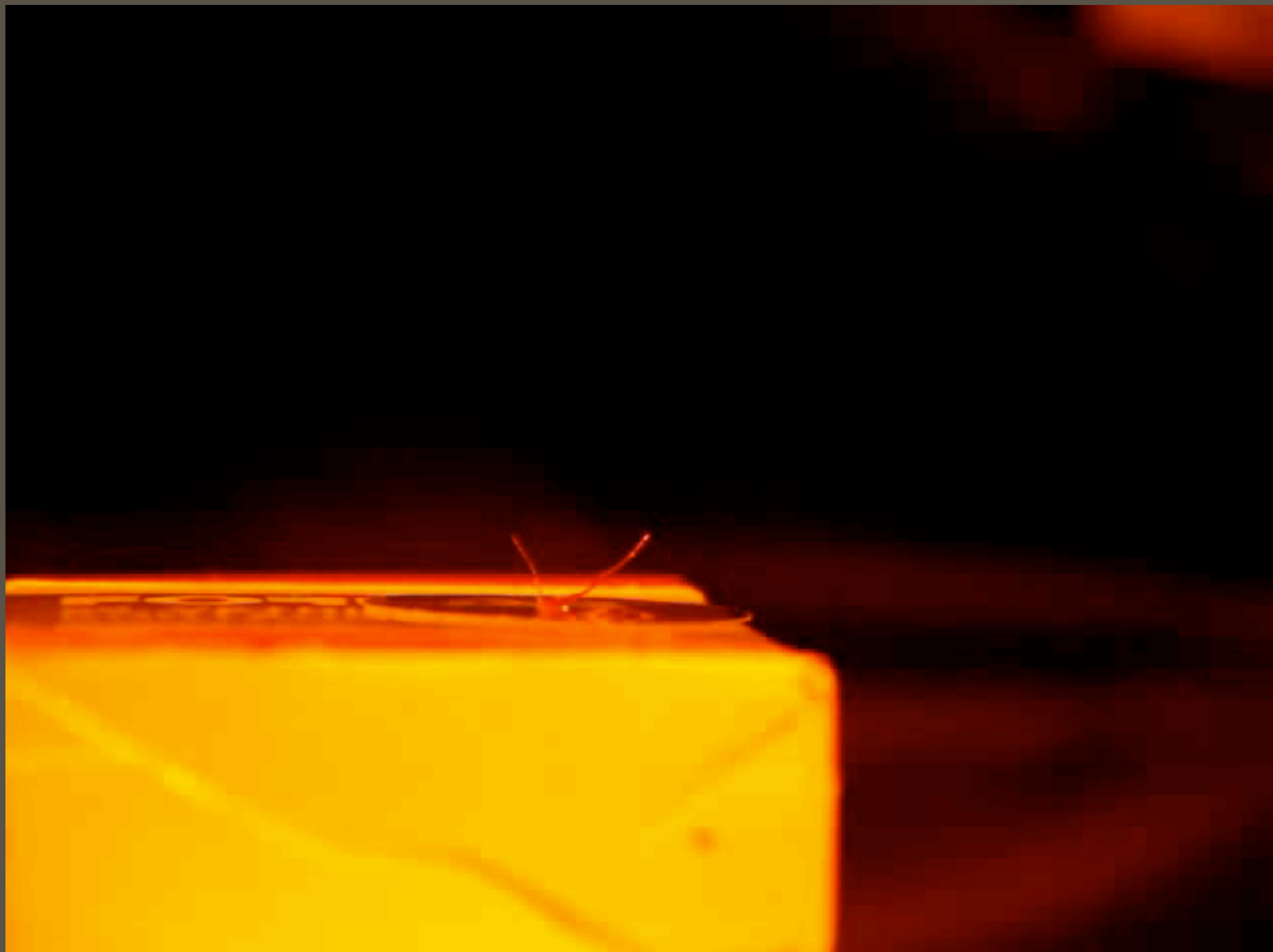
- 20-200 micron diameter, 5cm in length possible

Light driven rotation actuator



- 80 micron diameter twisted fiber

Light driven bending actuator

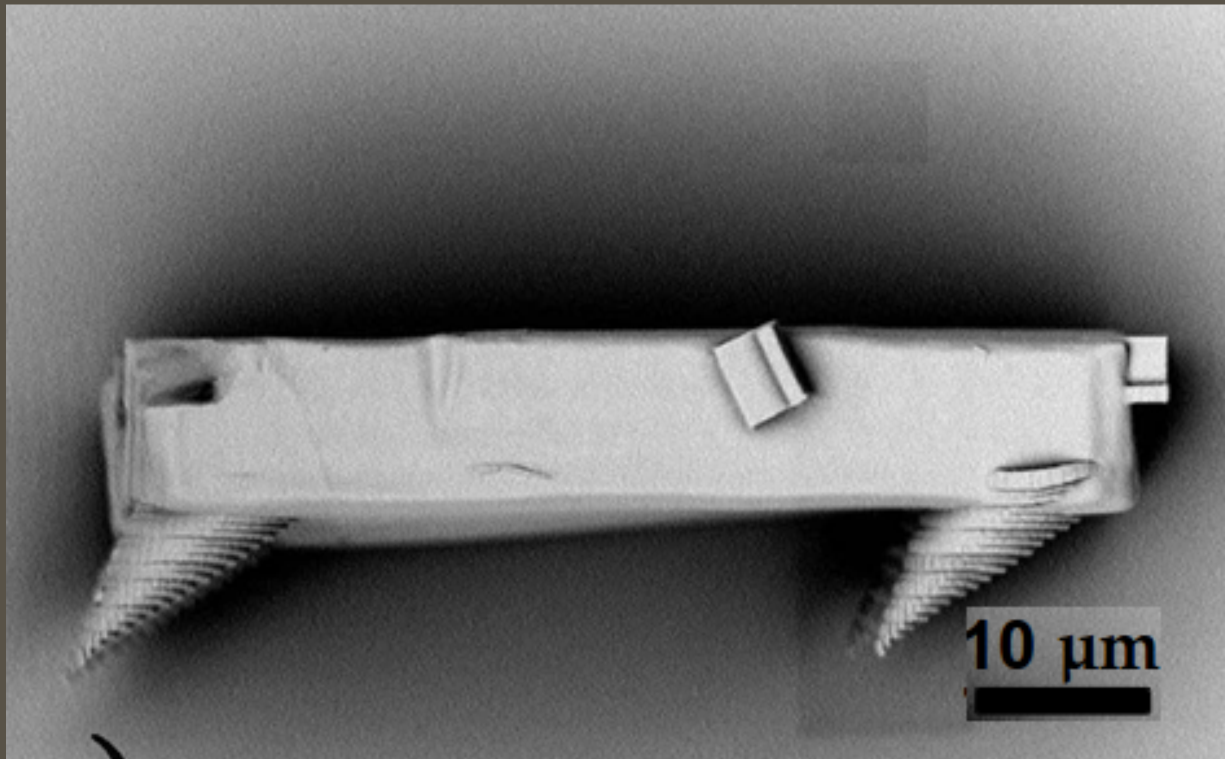


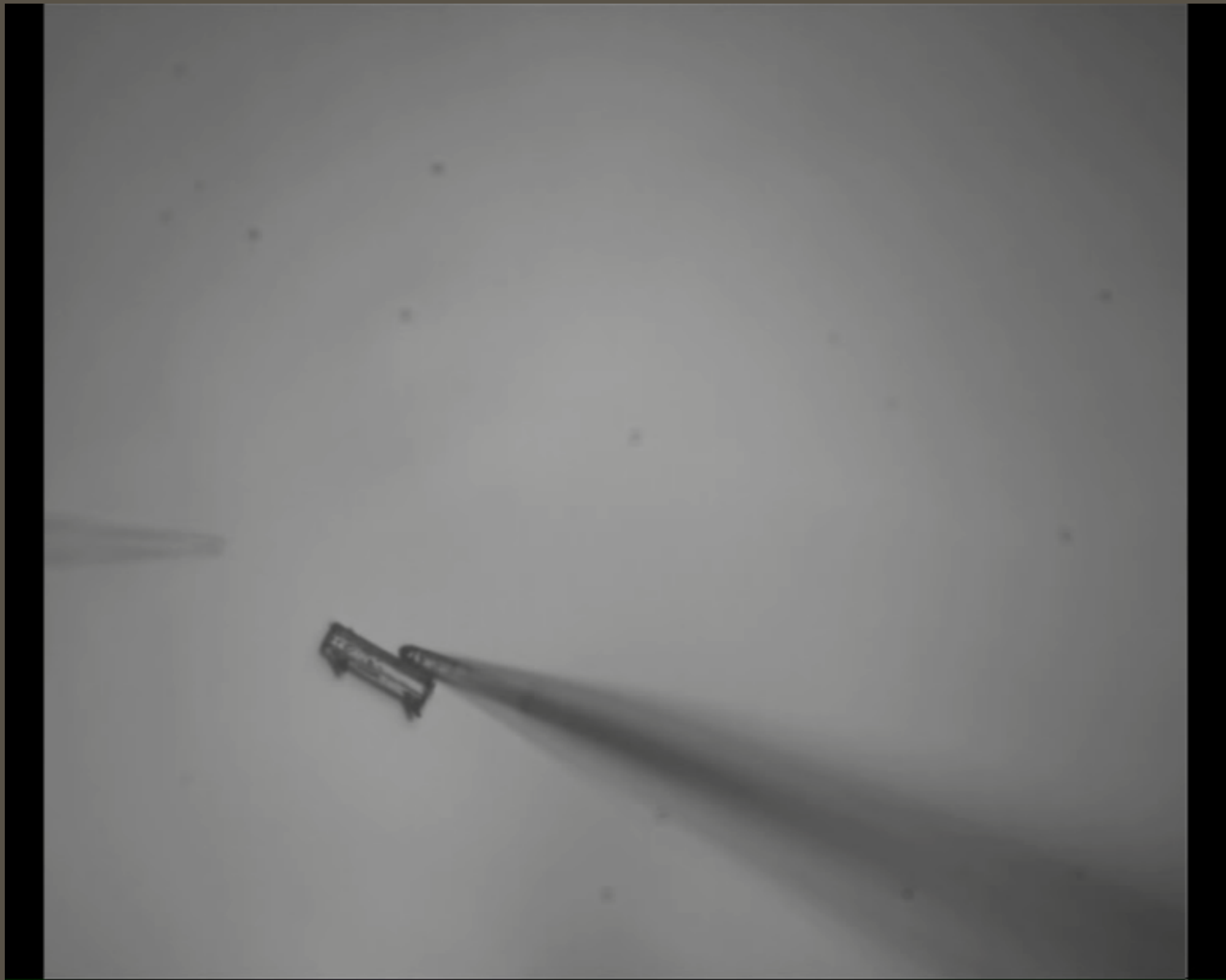
- Bi-layer of stiff material (IPL resin) combined with LCE

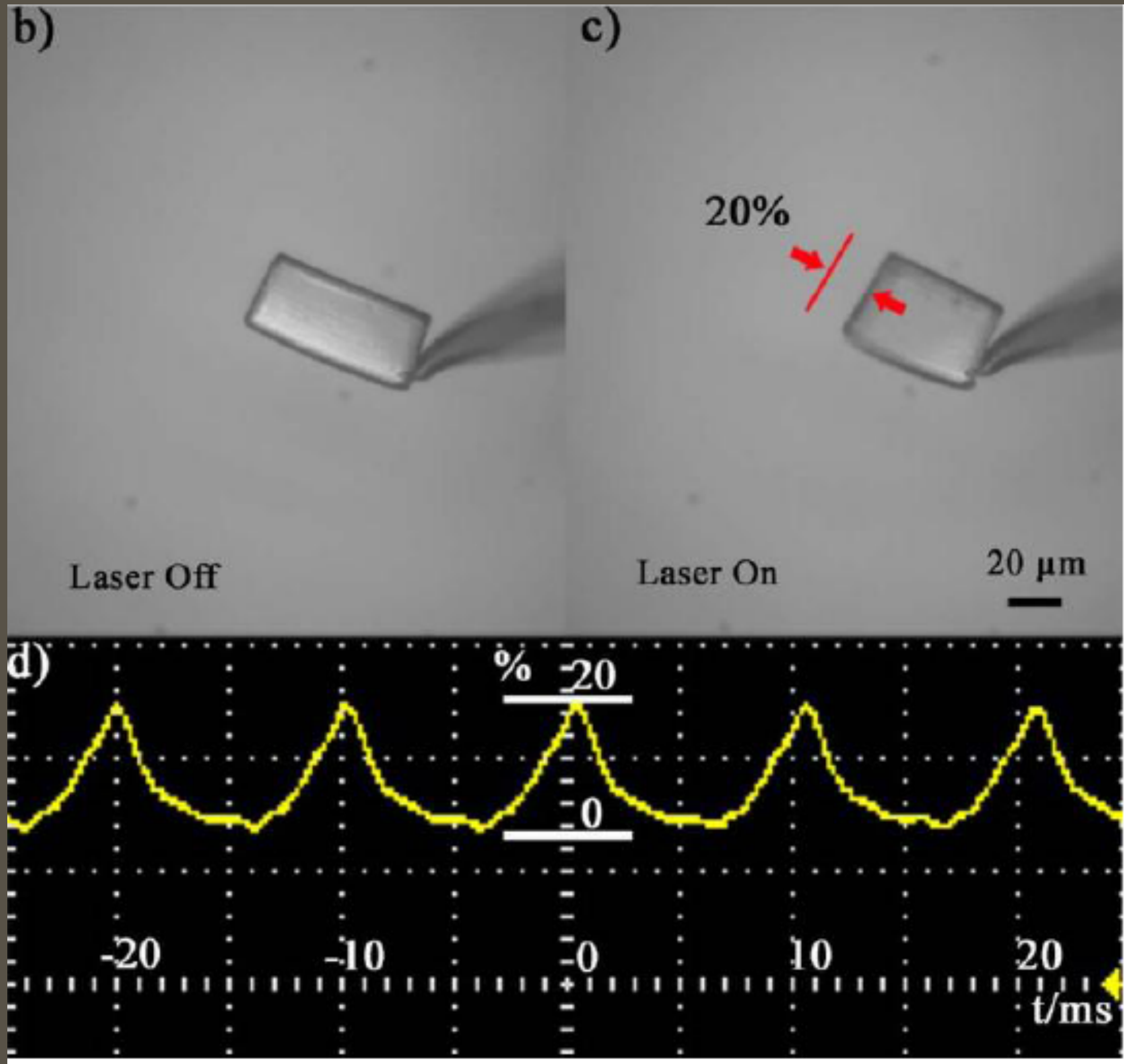
Small walking creatures

Frank Glaw et al., Microendemic Leaf Chameleons, Northern Madagascar (2012).

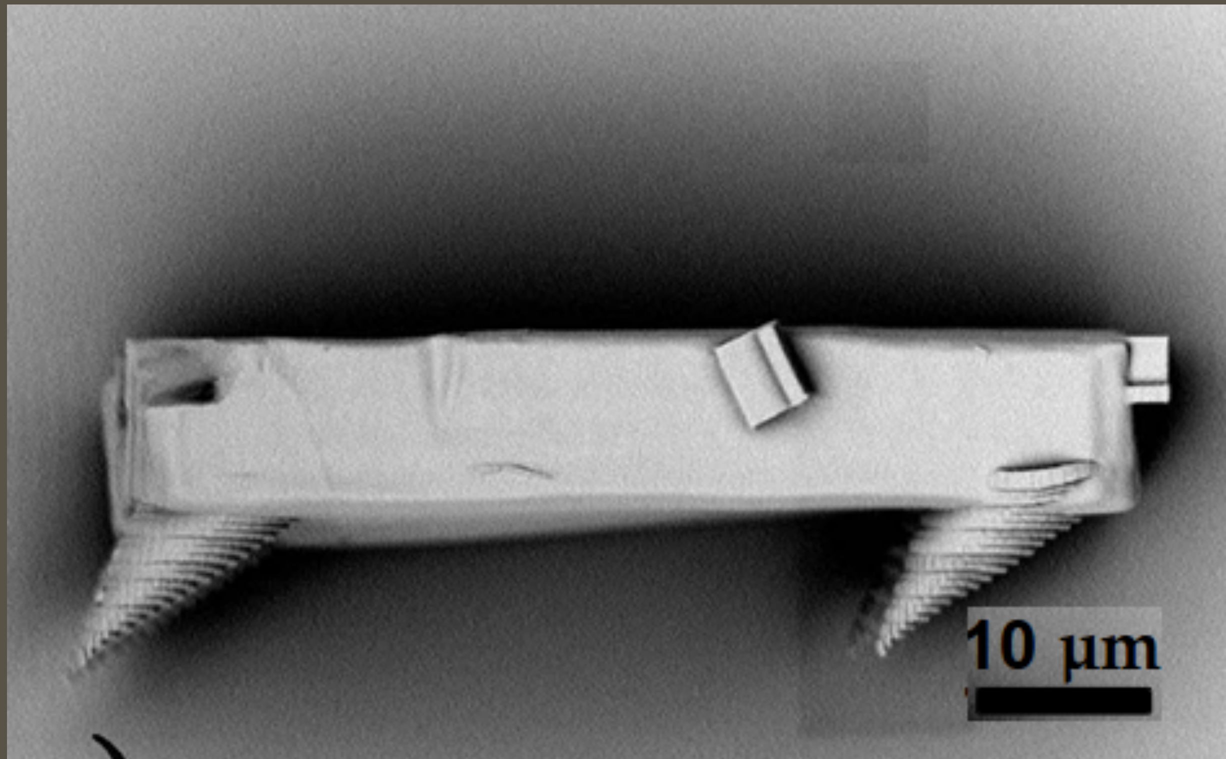
Light fueled microscopic walker

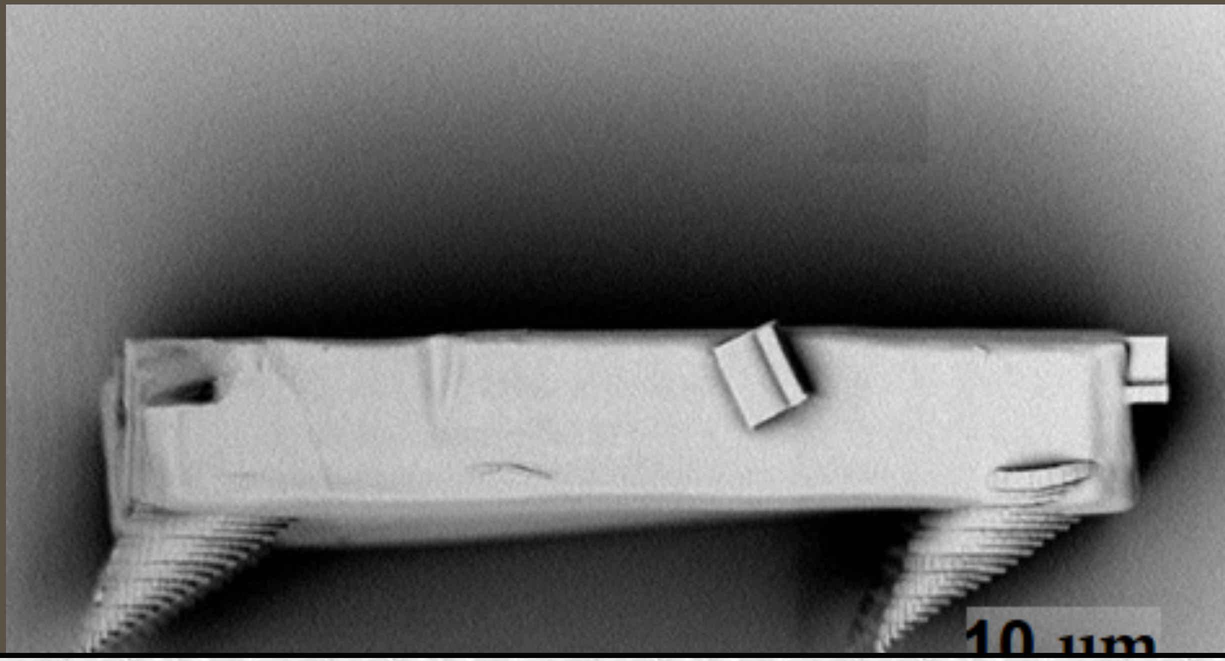


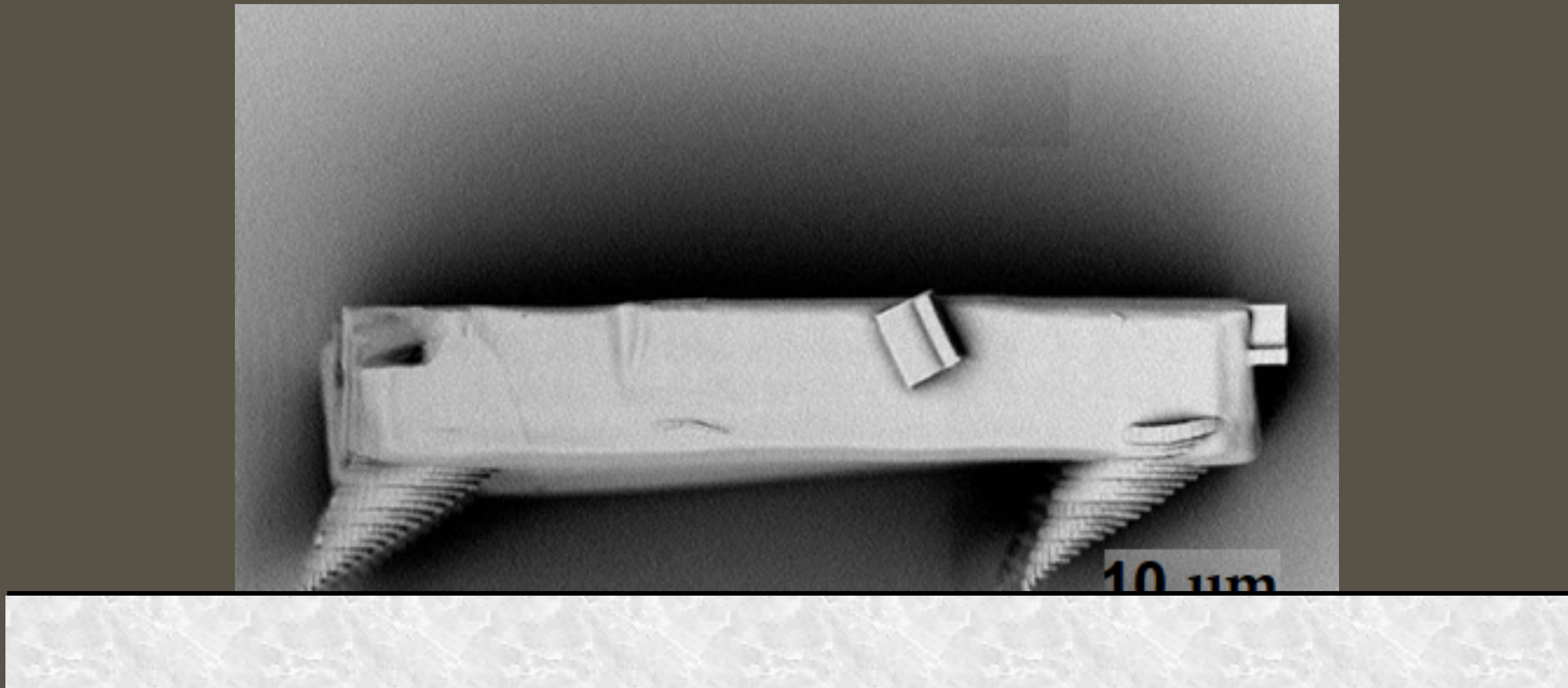




b)
c)
20%
Laser Off
Laser On
20 µm
d)
%
20
0
-20
-10
0
10
20
t/ms


10 µm

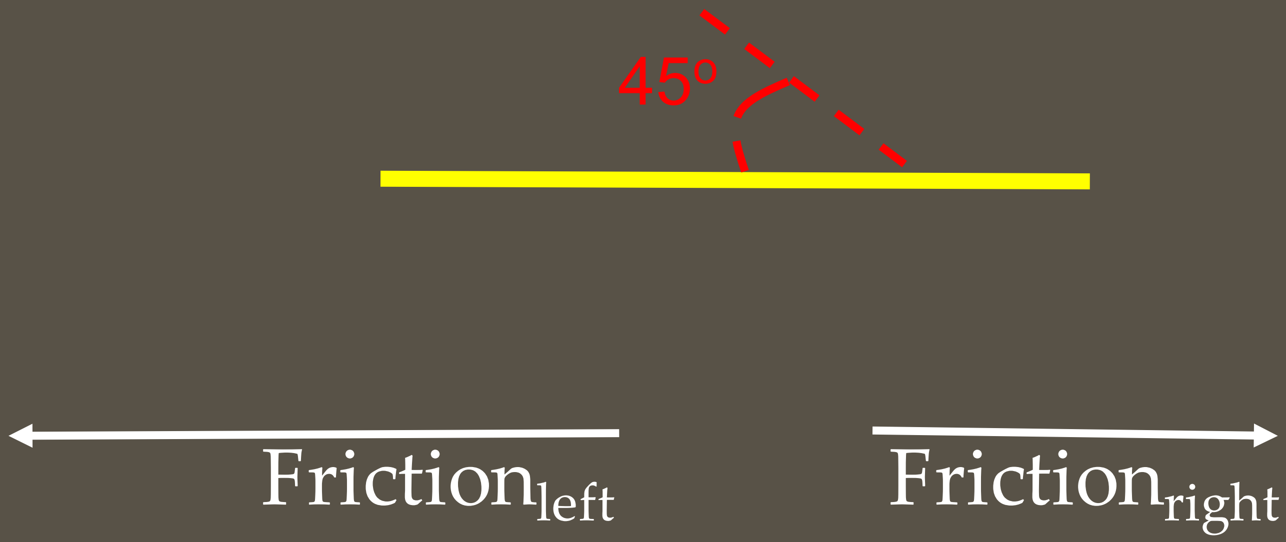

10 μm

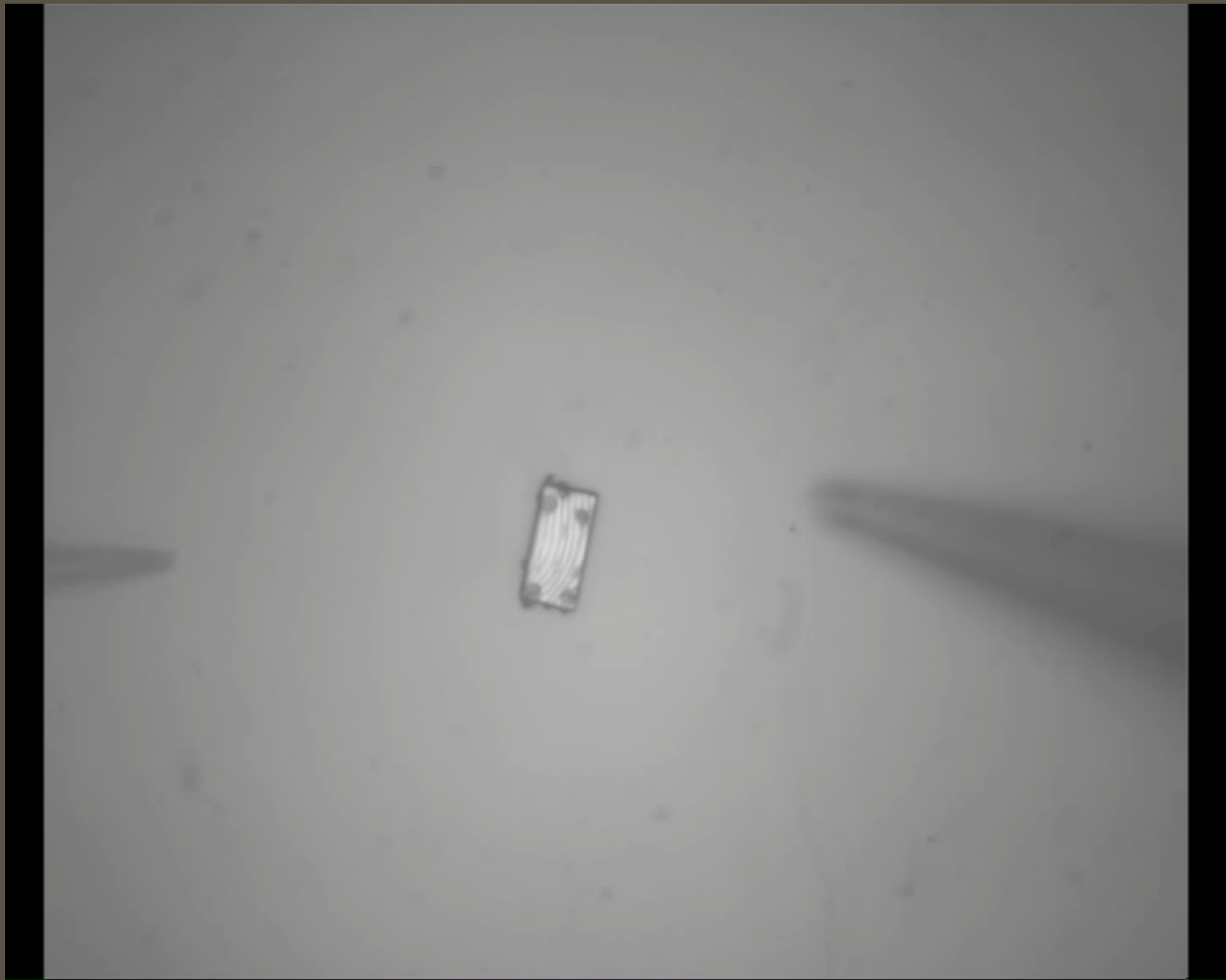


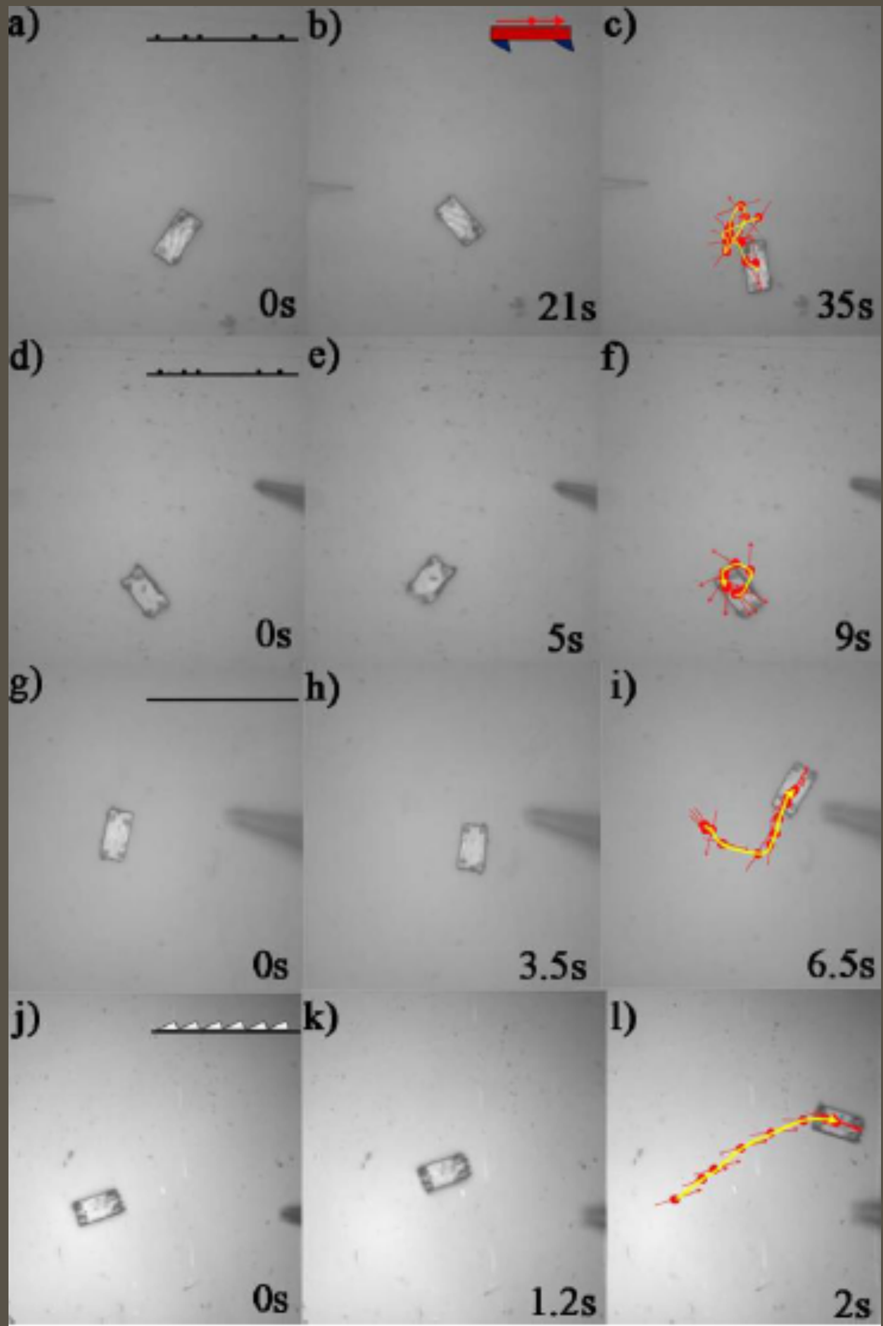
walking direction

"Gecko foot on glass" by Bjørn Christian Tørrissen

Friction due to van der Waals force



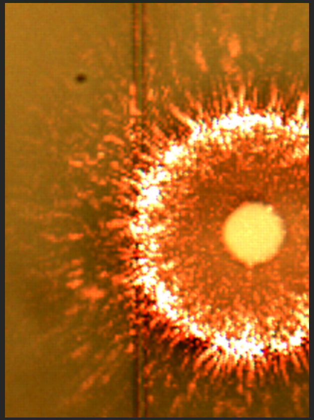



a)
0s
b)
21s
c)
35s
d)
0s
e)
5s
f)
9s
g)
0s
h)
3.5s
i)
6.5s
j)
0s
k)
1.2s
l)
2s

Conclusions

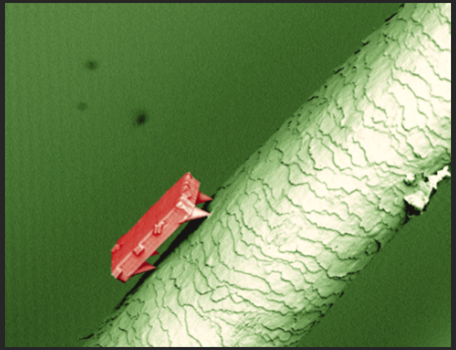
- Polymers and elastomers can be formed into high quality microstructures

    - Free form shape and local alignment
    - Photonic components
    - Light – deformation interaction and feedback



- Micro robotics with light

    - Smallest walking creature
    - Can contain photonic functionality
    - Energy from environmental light



The end