Selective surface fabrication using instability patterning

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Theory: Solar selective surfaces optimise the function of solar thermal devices in two ways. Firstly they absorb radiation across the wavelengths of maximum solar output. Secondly they reduce energy losses via radiation across the maximum wavelengths of radiative output according to their operating temperature (typically between 100° and 300°). At a given wavelength the emmittance and absorptance of a surface are equal. As a result, for an opaque material, emmittance and absorptance can be defined in terms of reflectance i.e.

$$\alpha = \varepsilon = 1 - \rho$$

$$where\ \alpha\ is\ absorbtance\ \ \varepsilon\ is\ emittance\ and\ \rho\ is\ reflectance.$$

As an ideal selective surface is highly absorbing across the solar spectrum and has low emission accros the infrared wavelengths its reflectance behaviour needs to change dramatically at around 2.5 microns as shown by Fig. 1 where it changes from having very low reflectance to very high reflectance.
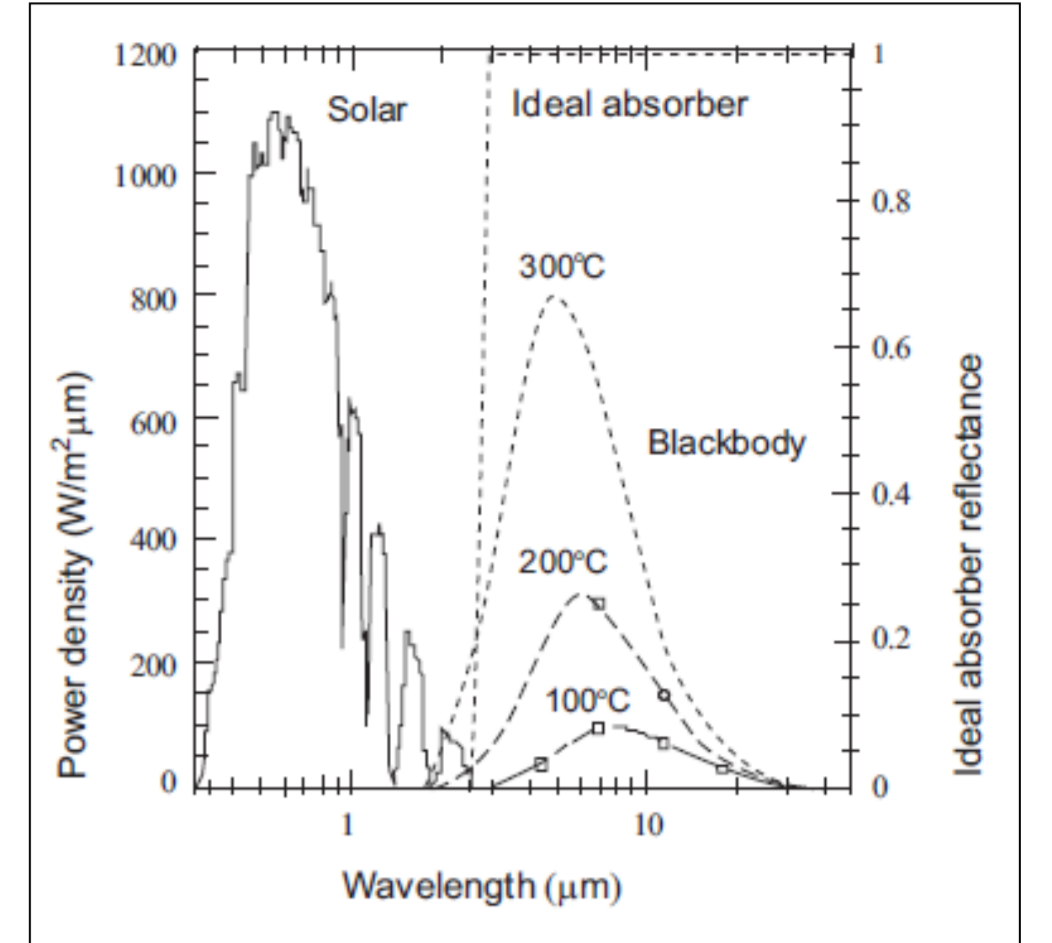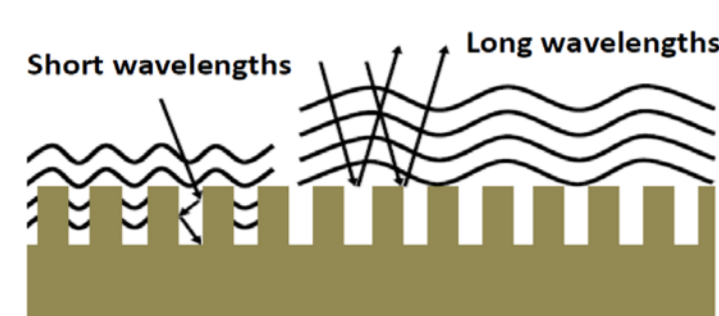

Fig. 1 Reflectance curve of an ideal selective surface adapted from [1]

Fig. 2 wavelength interaction adapted from [2]

Objectives: When radiation is incident upon a patterned surface the wavelengths which are comparable in scale to the scale of the surface pattern will interact with that surface. This is demonstrated in (Fig. 2) where the shorter wavelengths are absorbed as a result of multiple internal reflections, whilst longer wavelengths are reflected [2]. A coating is being developed that changes its reflectance behaviour at the objective wavelengths based on this prnciple.

Method: Instability patterning is used to create micro- scale arrays of 'pillars' (Fig. 3). One electrode of a capacitor is coated with a fluid. An applied voltage creates an electric field between the plates which destabilizes the fluid surface. This leads to the growth of structures which, over time, extend across the gap between the plates. The fluid is then solidified, setting the structures in place. Here a crosslinkable resin has been used, as it is chemically and mechanically stable, low in cost and can be shaped as a fluid then cured to form a solid.

Fig. 3 blue-electrode, red-spacer, yellow-fluid A. no applied voltage B. initial instability C. fully evolved structures

Fig. 4 shows the pillar array in the process of formation. Randomly distributed capillary waves, caused by thermal fluctuations in the fluid layer, are the initiation site for a pillar which then leads to further pillar formation around the initial pillar. This process can be seen in the middle of the image where a pattern of six pillars has evolved around a first.

The spacing λ of the pillars is given by Eqns 2 & 3. These show that by using a smaller electrode spacing and/or higher voltages, smaller-scale features can be fabricated. This is also achieved by other means with reference to the two equations such as by changing the dielectric constant of the epoxy material by adding fillers.
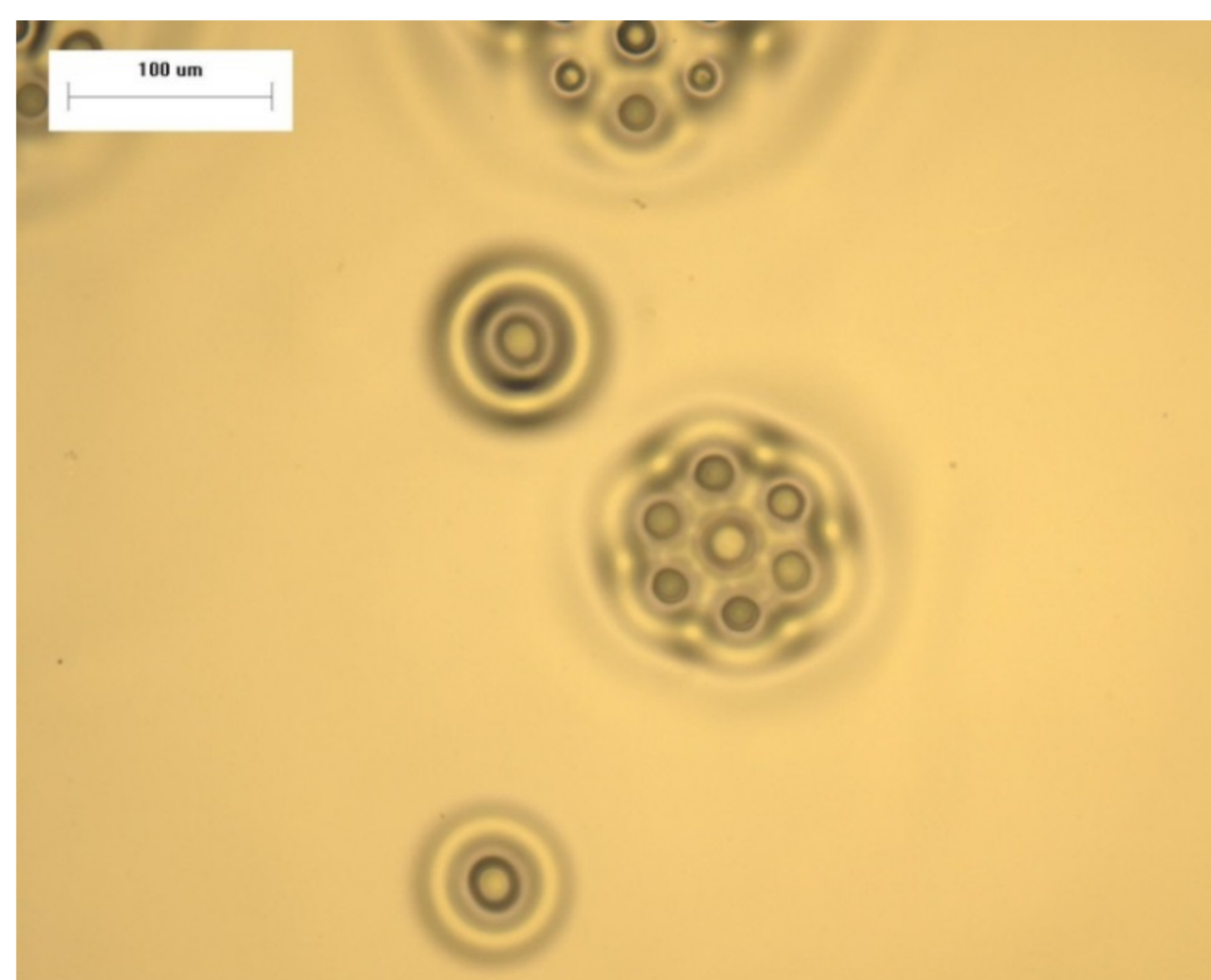

Figure 4 Pillar array formation

$$\lambda = 2\pi \sqrt{\frac{YU}{\varepsilon_0 \varepsilon_p (\varepsilon_p - 1)^2} E_p^{\frac{-3}{2}}}$$

$where\ Y = surface\ tension\ U = voltage\ \varepsilon_0 = vacuum\ permitivity$
$\varepsilon_p = relative\ permitivity\ of\ fluid\ E_p = electric\ field\ in\ the\ fluid$

Eqn. 2

$$E_p = \frac{U}{\varepsilon_p d - (\varepsilon_p - 1)h}$$

$where\ d = electrode\ spacing\ h = fluid\ thickness$

Eqn. 3

Results 1: Figs. 5 & 6 show the variation of the width and spacing of the pillars that occurs with different voltages for similar geometries.
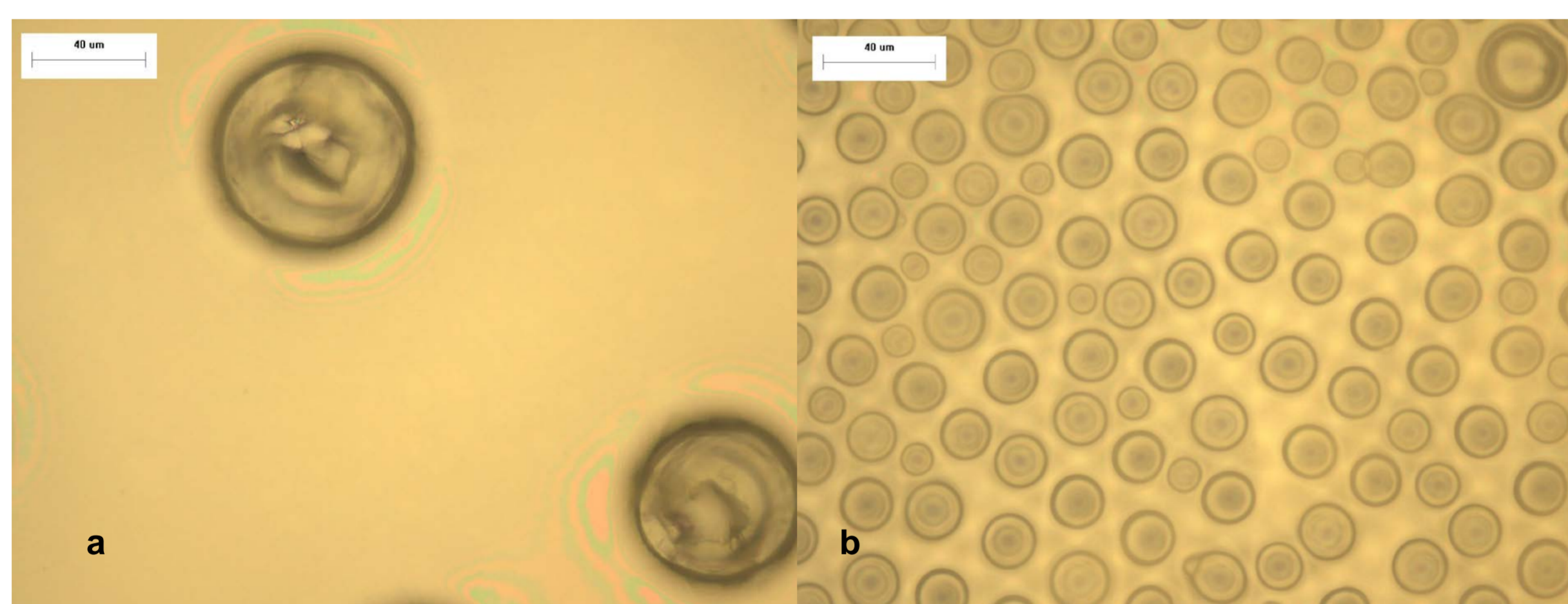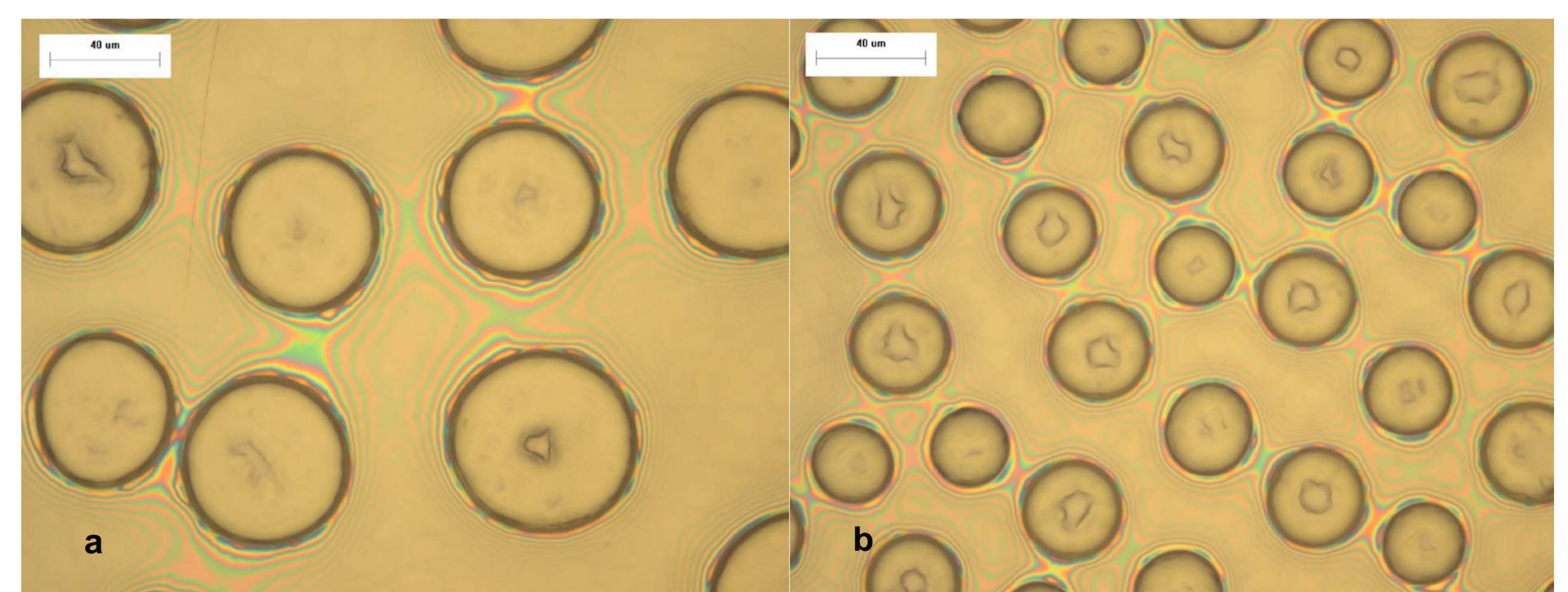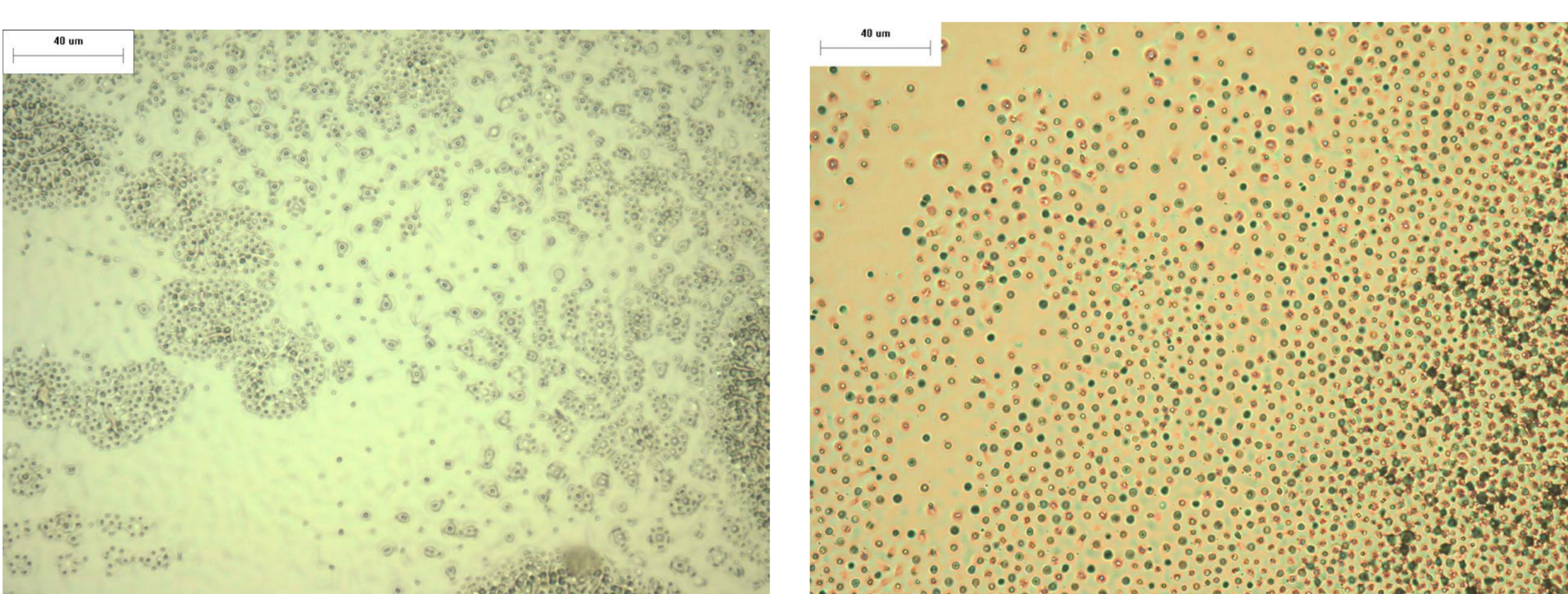

Fig. 5 a.125V b.162V

Fig. 6 a. 30V b. 60V

Fig. 8

Future work: Reduction of the scale of patterns are shown in Fig. 8. and the further reduction of the scale of the patterns is the object of continuing investigation using a variety of methods such as by altering the dielectric constant of the polymer material. The objective is to create patterns of around 2.5 microns in scale.

The use of filler materials is being explored as is the use of replacng the air gap with an ionic liquid as both of these methods have been used to crate smaller surface features in other materials [4&5].

Once smaller scale patterns are fabricated measurements of the reflectance of the reduced scale patterns will then be taken.

References

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