Supplementary Information for: Inkjet Printing of Structurally Coloured Self-Assembled Colloidal Aggregates

Pavel Yazhgur,*,† Nicolas Muller,‡ and Frank Scheffold*,†

†Department of Physics, University of Fribourg, CH-1700 Fribourg, Switzerland
‡iPrint Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland, Fribourg CH-1700, Switzerland

E-mail: pavel.yazhgur@unifr.ch; frank.scheffold@unifr.ch

Number of pages: 10
Number of figures: 9
1 PB size distribution

Figure S1 shows the size distribution of photonic balls as measured using scanning electron microscopy. For all studied NP sizes, the PB diameter distributions stay akin. The mean PB diameter stays around $D \approx 1.1 - 1.4 \, \mu m$, with the mode value being around $0.9 - 1.1 \, \mu m$. The polydispersity is around $25 - 35\%$.

![Figure S1: Size distribution of photonic balls as measured from SEM images for various NP sizes.](image-url)
2 Angular-resolved optical spectroscopy

To characterize the angular color response, we have used a laboratory-made optical set-up. A collimated beam (Ocean Optics HPX 2000 white source) with a spot size around 5 mm (at normal incidence) is used to illuminate the sample. The reflected light is collected by an optical fibre (Ocean Optics, QP400-2-SR-BX) connected to the spectrometer (Ocean Optics, FLAME-T-XR1-ES). Two goniometers allow us to independently control the orientations of sample and detector in respect to the incident beam. We calibrate the spectra by measuring Lambertian white standard as a reference. Two main measurements configurations, depicted in Figure S2 a) and b), allow us to explore diffuse and specular reflections. The measured spectra are transformed to perceived colors using Colour Science python package.\(^1\) In Figure S2, we demonstrate the obtained colors for blue, green and magenta deposited films and various observation angles (angle between the incident beam and the detector.) One can see that by varying observation angle, the hue remains almost constant. By plotting the peak position as a function of the observation angle, all data collapse on a single master curve. The remaining angular dependence has been previously described for structurally colored materials, in particular photonic balls,\(^2\) and should not strongly influence color non-iridescence.

3 Humidity test

To demonstrate the stability of the printed colors, we perform humidity tests. To this end, we compare the color response of the deposited films at room humidity (48%) and in a closed container with water at the bottom (relative humidity 94%). As shown in Figure S3, humidity has no visible effect on color response of deposited films.
Figure S2: Angular dependence of the acquired structural colors of the deposited films. The schemes depict two measurement configurations: diffuse (a) and specular (b) reflections. The perceived colors as predicted from the measured reflection spectra for various observation angles (defined as an angle between the illumination and detection directions). c) Normalised peak wavelength position as a function of the reflection angle for various films (red, green and magenta) and measurement configurations (open squares for diffuse reflection and open triangles for specular reflection)
Figure S3: Photos of deposited colored films at room conditions, relative humidity 48%, (a), (c), (e) and in a closed container, 94%, (b), (d), (f). All experiments are performed at room temperature (24 °C).
4 Influence of printed layers number

In Figure S4, we demonstrate the dark field microscopy images of inkjet printed samples for 10 and 40 passes. One can remark a clear increase in the surface coverage with number of passes. Though, the printed samples reveal some distinct regions at the lengthscale of tens of microns, this inhomogeneities can hardly be observed by a naked eye. We remark, that the obtained coverage is enough to create prints with fine details, as, for example demonstrated in Figure S5.

Figure S4: Microscopy photos of printed cards (top row - NP-diameter $d_{NP} = 206$ nm, bottom row - NP-diameter $d_{NP} = 270$ nm) for 10 (a), (c) and 40 (b), (d) passes.
5 Substrate optimisation

We have successfully demonstrated that photonic balls can be printed on glossy substrates, matt black paper, and glass slides. We managed to create fine lines on all the substrates mentioned above. As shown in Figure S5, the matt black paper has the lowest reflectance, which results in the most pronounced colors.

Figure S5: Photos of green and red PB films on various substrates (from left to right): matt black paper, glossy black paper, microscope glass slide. Reflection spectra of films and substrates. A right to use the University of Fribourg logo has been granted.

6 Waveform Tuning

The waveform is the time evolved voltage profile, sent to a printhead and stimulating the piezoelectric elements. Before the printing test, the waveform needs to be tuned. Correct waveform tuning enables control of the ejected drop speed and the circumventing of satellites. The chosen waveform is shown in Figure S6.

Once the waveform is chosen, the acoustic optimum needs to be determined. The latter one consists of the dwell time of the central plateau for which a given waveform transmits the most kinetic energy from the piezoelectric elements to the ink. In the case of a Seiko
Figure S6: The waveform consists of a square profile with a dwelling plateau in the central region.

RC1536-L printhead and a 0.4% PB-loaded ink with pentanol as a solvent, the acoustic optimum is found to be at 5.3 $\mu$s as shown in Figure S7.

![Figure S7: The acoustic optimum for a 0.4% PB-loaded ink with pentanol as a solvent is determined to be 5.3 $\mu$s.](image)

It should be noted that by changing the excitation voltage from 18 V to 23 V, it is possible to generate a pulse that ejects one drop at 2.8 m/s with a drop volume of 10 pL or two drops at six m/s, each one with a volume of 9 pL, as shown in Figure S8.
Figure S8: Dropwatching performed with the same waveform and acoustic optimum. On the left the excitation voltage was set to 18 V and on the right to 23 V, resulting in the generation of one drop or two drops per pulse.

Figure S9: Absorption spectra of CB dispersion in dimethyl sulfoxide as measured using UV-VIS Jasco V-670 spectrometer.
References

(1) Colour Science Version 0.3.16. https://www.colour-science.org/, (accessed 2022-05-01).

(2) Ohnuki, R.; Sakai, M.; Takeoka, Y.; Yoshioka, S. Optical characterization of the photonic ball as a structurally colored pigment. Langmuir 2020, 36, 5579–5587.