Abstract T-01

T-12: Printing and Generating Structural Colors by means of inkjet technology

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Abstract

In the context of Industry 4.0, inkjet technology has the unrivaled advantage of being digital and versatile by its nature.
The recent breakthrough in the understanding of structurally colored materials provides new design platforms for pigments in a variety of applications. An appealing approach is the design of photonic pigments for inkjet printing.
However, inkjet technology imposes strict limitations with respect to pigment size.
Here we show the deposition and the fabrication of photonic pigments by inkjet technology.

Keywords*:inkjet technology, photonic pigments, nanostructures, bandgap materials*

1. Introduction

Over the last decade, tremendous progress has been achieved towards the understanding of structural coloration both from crystalline and non-crystalline materials (4), (5). The latter are of particular importance since they provide non-iridescent stable coloration, which is similar in appearance to conventional dyes and thus often preferred. Having no chemical pigments, structural colors never age, stay ultra-resistant to bleaching and can be manufactured from low toxic materials, thus having much lower environment and human health impacts. The delivery or deposition of the materials remains however a major hurdle towards practical applications such as graphical printing. One way to overcome these problems is to confine first nanoparticles inside emulsion droplets to produce micrometer sized clusters of photonic crystals (3) – "photonic balls" (PB), and then use the obtained colored ink for practical applications (2) in the domain of inkjet printing.

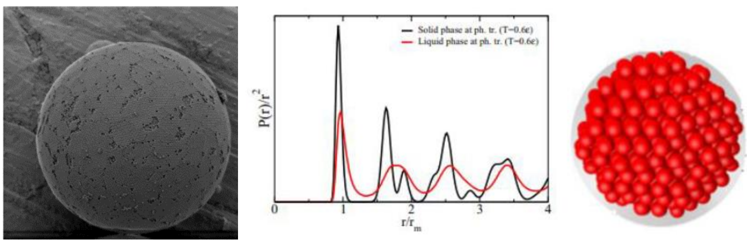

Fig. 1. Left: Experimentally fabricated Photonic Pigment, Right: Numerical Simulation of a particle filled droplets, black/ red line denote amorphous solid/liquid structure near close packing conditions

2. Theory

Ordinary pigments that are used for color formation in clothes, paintings, etc. usually start to fade and to bleach after a certain lifetime. In most pigments, molecules absorb incident white light over a certain spectral range and the reflected or transmitted light acquires the color of the light that is not absorbed. During this process the molecules slowly degrade or bleach and the color intensity diminishes. This is why other color forming systems are sought after. One way to achieve this is by using systems that generate color by interference, meaning that a physical system presents structural properties such that certain wavelengths constructively interfere. This range of wave vectors that are not allowed to penetrate inside the system and are reflected back, similar to a mirror, is called a photonic bandgap. The corresponding wavelengths, for a given angle of illumination, give rise to what is known as iridescent colors; colors that are very bright but highly angle dependent. Wavelengths outside the photonic bandgap mainly penetrate the structure without being altered. The central wavelength at which the bandgap is located and by this defining the color, depends mainly on three parameters: the size of the underlying crystalline lattice, the refractive index of the units that form the system and the incidence angle.

Recently it was shown that disordered, but highly correlated, systems can also produce color. Being intrinsically disordered, their photonic bandgap is completely isotropic, meaning that the resulting colors are not angular dependent.

By carefully organizing spherical submicron-sized particles, for example made of polystyrene, it is possible to generate colors. Such structures are in the following referred to as photonic balls. The colors that such photonic balls produce depend mainly on the size and the refractive index of its sub-unit particles. Different colors can be achieved by carefully tuning the size of these sub-unit particles. The colors that arise from these photonic balls are isotropic, which is a major advantage compared to purely periodic systems.

Moreover, such systems are formed by sub-unit particles of around 200-300 nm, and to achieve color effects they need to be assembled in photonic balls of a size in the micrometer range or larger. This adds additional challenges when depositing them with standard inkjet technology. The nozzle of state of the art printheads range from 10-50 um, meaning that the acceptable pigment size is around 1-5 um. To cope with these challenges a customized printing platform is used together with an adequate printhead. The platform is able to handle these photonic ball loaded inks from a fluid supply point of view (recirculation to avoid sedimentation and agglomeration) as well as from a printhead point of view with the best possible performance.

3. Experimental procedure

Structural colors are easily obtained in colloidal suspensions of repulsive spheres as shown in the work on structural coloration ('photonic liquids') dating back to 2004 (1) or thin nanoparticle films. Droplets with low volume fraction of nanoparticles are first formed and the solvent is then removed from the interior of the droplets. In order to do so, the classic approach of removing solvent in a controlled manner by osmotic solvent-extraction drying was employed in this work. Decanol was chosen as the appropriate solvent.
The as-formed photonic particles are then dispersed in pentanol and subsequently jetted with a state of the art industrial printhead (Ricoh Gen4, Seiko RC1536).

4. Results and discussion

First, thin films were deposited with a 50 um homogeneous film spreader in order to evaluate color formation. It was found that multiple scattering dominated, resulting in a white appearance. Incorporating small amounts of carbon black inside the photonic balls resulted in the suppression of multiple scattering and lead to the appearance of the desired photonic color.

Figure 2. Dried films of photonic balls.

In a second step, the as-formulated inks were printed by means of inkjet printing.

Figure 3. Photonic balls printed by means of inkjet technology. Left: Redish color. Right: Greenish color

In addition, we show an alternative route to fabricate photonic pigments of spherical and disk-like shapes. To this purpose, an industrial printhead is employed as a micrometer drop generator. The as-formed drops are jetted on a decanol surface, which will extract, via osmotic pressures, the water from inside the droplets. Due to geometrical constraints disk-like particles are formed.

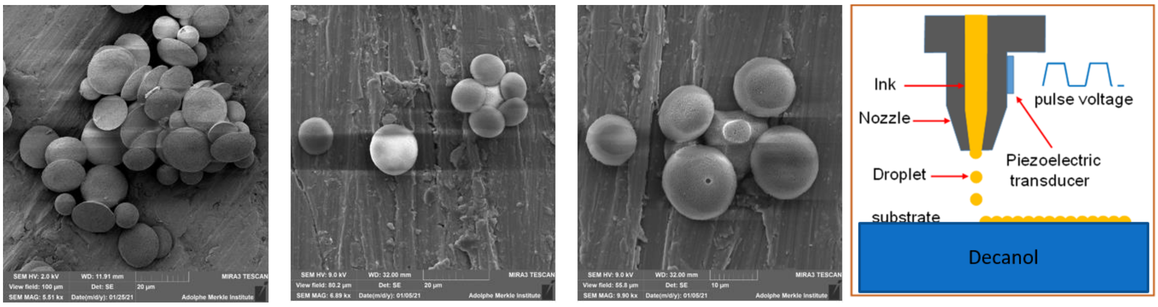

Figure 4. Photonic pigments of disk-like shape, fabricated by jetting a PS nanoparticle suspension on decanol.

Moreover, drops are jetted into air and drying was achieved in the gas phase, resulting in photonic pigments of spherical shape.

5. Conclusions

We have shown the reproducible deposition of um sized photonic pigments by means of inkjet technology. Color intensity was enhanced by incorporating carbon black into the photonic balls, thus supressing multiple scattering.
Moreover, the photonic pigments, manufactured with this novel method, present a higher degree of monodispersity, form highly uniform color and can be readily scaled in diameter according to the desired field of application.

6. References

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