Inkjet Printing Structural Colors based on Plasmonics

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Inkjet printing is a wide-spread coloration technique for home applications, but also for high-end graphics and security elements. This work demonstrates novel color effects based on inkjet printing that circumvent some of the drawbacks of the typically used chemical dyes, such as photobleaching and smearing. Utilizing a plasmonic foil as a substrate and applying transparent inks of varying refractive indices allows the creation and control of structural colors with conventional equipment like desktop inkjet printers and any drawing program. Apart from private users, this technology could be attractive for advertisement, security and brand protection due to the simple, digital serialization of pictures or numbers.

Inkjet printing is one of the most common processes in the graphic industry. Nowadays, such techniques are by far not limited to classical dyes though; research on metallic and dielectric nanoparticle inks are for example on a steep rise. Inkjet print-heads are still constantly evolving, as higher accuracy, faster printing speed or lower material consumption are highly sought-after. Furthermore, novel concepts such as 3D printing have been implemented in the past decades.

Coloration using inkjet is typically based on chemical dyes or pigments, which are prone to photobleaching and smearing when coming into contact with water or grease. Further, the color space available is limited and no metallic gloss, matte finish or actively tunable coloration can be achieved with classical inks. In contrast, structural colors as found in nature on various butterflies or beetles for example do not have these drawbacks. Unfortunately, they are much more difficult to realize and control on an industrial level. Typically, pictures have to be defined lithographically on a nanoscopically patterned master and cannot be adapted in a simple fashion. Combining inks of varying refractive indices and plasmonic nanostructures sensitive thereto might solve this problem.

In the present experiments, a plasmonic substrate consisting of U-shaped aluminum nanowires was chosen. The resonances found in such structures are very sensitive to the refractive index of the surrounding media; it is therefore possible to change the resonant wavelength by adapting the coating material. In other words, by dispensing inks of different refractive indices, it is possible to locally control the color of the plasmonic substrate. It is worth noting that, for this specific system, only one of the linear light polarizations is capable of exciting the plasmonic resonance.

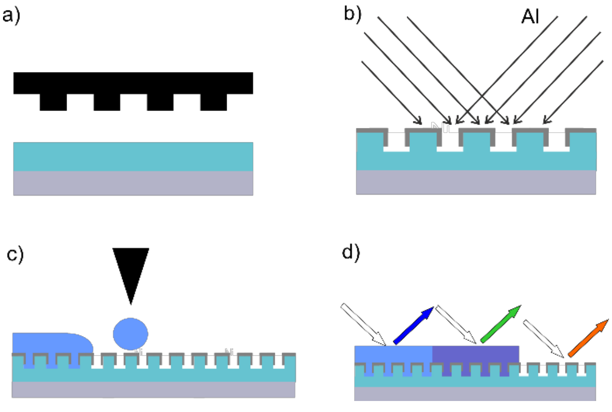

Figure 1: Schematic showing the experimental procedure.

The plasmonic substrate can be obtained by replicating a binary grating either by UV casting or hot embossing into a polymer substrate (Figure 1a) and subsequently evaporating it with aluminum from both sides (Figure 1b). Through self-shadowing of adjacent ridges, disconnected wires are formed. Finally, an inkjet printer is used to dispense a transparent high refractive index material onto the plasmonic substrate and hence form a colored picture (Figure 1c and d).

Figure 2: A plasmonic structure, bearing a volleyball player inkjet printed with high refractive index material, photographed in two different linear polarizations of light in two orientations.

Figure 2 depicts a volleyball player printed in this manner. Note that due to the polarization sensitivity of the substrate, the coloration of the picture strongly changes when observed through a linear polarizer (compare top to bottom pictures). This is true for the air interfaced part as well as for the printed part. For the present 1D structure, orientation of the sample is also important for its appearance as clearly visible in Figure 2. This tunable appearance of pictures is essential for visual applications like anti-counterfeiting and clearly not achievable with conventional inks and substrates. It is finally worth noting that large areas of homogeneous plasmonic nanostructures can be fabricated with high-throughput processes as they are roll-to-roll compatible. The printing technique could also be incorporated into such industrial fabrication lines, but is even exploitable by private customers with commercial desktop inkjet printers (as the one used in this report).

In summary, it was demonstrated that inkjet printing of dielectrics can be used to locally control the refractive index on a plasmonic substrate and thereby the resulting structural color. Since homogeneous plasmonic substrates can be fabricated with large-area, cost-efficient roll-to-roll manufacturing, customizing such structures with an established process like inkjet printing has a high potential for private, but also industrial applications and could even find its way into mass production of everyday products for decorative or anti-counterfeiting purposes.