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Designing Nano-Media: How to Build a Novel Media Surface with Extraordinary Optical Effects and Data Storage at the Nano Scale

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Abstract

This project explores and expands modes of expression in media arts and communication practices through the development of nanotechnology and nano-manufacturing processes. The demonstration showcases techniques, prototypes and possible applications of 'nano-media,' from publishing and security to interactive wearable fabrics and entertainment. This new kind of media surface uses nano-sized pixels to produce extraordinary optical effects for displays while also storing analog or digital data, fusing the instruments and matters of vision and information. Emerging from technology developed for security/authentication, our ongoing collaboration with artists and media scholars has resulted in scientific and aesthetic breakthroughs in the field of nano-optics by drawing inspiration from many analog media techniques, such as Dufay color film. Here we show examples of our ongoing developments.

Keywords

nano-optics, optical variable devices (OVDs), plasmonics, pixels, nanofabrication, imaging and data storage, art-science, new media

Introduction

Nano-media is a new kind of media surface that develops and uses a novel prefabricated material comprised of nanostructures that allows—concurrently—for exceptionally high resolution display, the covert/overt encoding and storage of data, and the integration of interactive functionalities. It is produced using the accompanying processes of nanofabrication and multimedia information representation, encoding, sensing and interactive communication.

When functional optical pixels based on nanostructures are prefabricated into a material such as polymer (plastic), paper, glass, metal, or other tissue/fabric, they form a nano-substrate. When this nano-substrate is patterned to store information and integrated with additional functionalities, it produces what we call 'nano-media'. Nano-media is a surface that has unique optical qualities that 1) produces special visual effects (e.g., optically variable devices and screens); 2) can contain covert information that can be read using devices like smartphones; and 3) can be integrated with additional functionalities such as sensing and actuation. These image, data, and interactive functionalities are integrated with the pixelated pre-fabricated nano-substrate using high throughput nano-imprint lithography, mature microscale patterning techniques or recently-developed functional inkjet printing. The prefabricated pixels (nano-substrate) can be activated in specific ways depending on the intended functionality(ies). Our process of easy activation of prefabricated pixels is unique and provides personalization options previously unattainable in the realm of nano-optics and our previous research [1] [2].

Our first application of this new nano-media concept and its nanofabrication processes was developed in collaboration with the artist Christine Davis and postdoctoral fellow in media studies Aleksandra Kaminska. Our goal was to produce a cover image for the arts periodical *PUBLIC*: Art/Culture/Ideas.[1] We provide a technical overview of this specific project, as well as of our more recent advances, and we demonstrate how an image and data can be easily 'translated' into nano-media.

Nano-media produced by stacking intensity control layer on nano-substrate

Nano-media can potentially produce color images up to 12,700 pixels-per-inch (PPI) in a variety of materials, including metal, polymers, paper and textiles. Nano-media can be simply produced by stacking an intensity control layer (ICL) on top of a pre-fabricated nano-substrate [3] [4] [5]. The nano-substrate is comprised of structural pixels. These include RGB (red, green, blue) pixels that are tuned to produce any color, and IR (infrared) pixels that are used for invisible information (storage). The ICL is a static layer to control the amount of light that can effectively output from each pixel. Therefore, any visible color can be achieved by appropriately mixing of the red, green and blue colors in a certain ratio. The information embedded

[1] For a detailed account of this collaboration, see Aleksandra Kaminska's paper in these proceedings.

into the nano-media is solely determined by the ICL while the nano-substrate is generic. Large quantities of nano-substrate can be pre-fabricated using a roll-to-roll imprint technique and each piece of nano-substrate can be used to store information, either analog or digital, or the combination of both. Figure 1 shows a nano-media sample, with a visible color picture combined with a hidden QR code. The QR code is not visible to human eyes but can be read with an infrared reader.

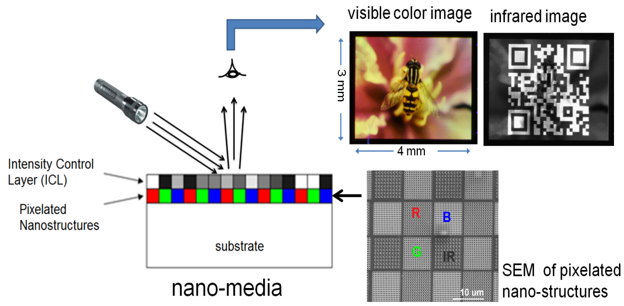

Figure 1: Nano-media produced by stacking an intensity control layer on top of a nano-substrate. Picture adapted from reference [3] [5].

Nano-media produced using optical lithography

As an alternative to the stacking approach, nano-media can be produced by implementing optical lithography techniques to selectively activate or deactivate pixels from a nano-substrate [6]. Optical lithography allows for patterning nano-substrate with resolution better than 1 um. Figure 2(a) shows examples of a nano-media sample produced using this kind of photolithography, as was used in *PUBLIC*. To produce this sample, a binary photomask was first produced according to the color pattern and the photomask was aligned to the pixels on the nano-substrate. The photolithography process activates only the wanted pixels through the photomask and the activated pixels are transferred to a flat transparent polymer sheet using UV-nanoimprint. The produced image can also be used as an image stamp for roll-to-roll replication to reproduce the same image in large quantity.

In this technique, the nano-substrate can be reused: a wet chemical removes the materials on top of the nano-substrate and it is ready to be used for producing a different color image.

We have also implemented maskless laser lithography to produce high-resolution samples, for example of Van Gogh's famous painting *Starry Night,* as shown in Figure 2(b). To write this painting on the nano-substrate, the RGB values for each pixel were translated into variable sizes of apertures on the RGB subpixels and the pattern of apertures were exposed onto the nano-substrate using a laser writer (Heidelberg µPG 101 Laser Writer). After exposure the photoresist was developed and the image was transferred to a flat transparent polymer sheet using UV-nanoimprint. In this sample, the size of effective pixel is as small as 20 um and the image resolution can reach 1,270 PPI. The fine details of the whole painting are revealed within a 4 mm × 3 mm sample area.

a) b)

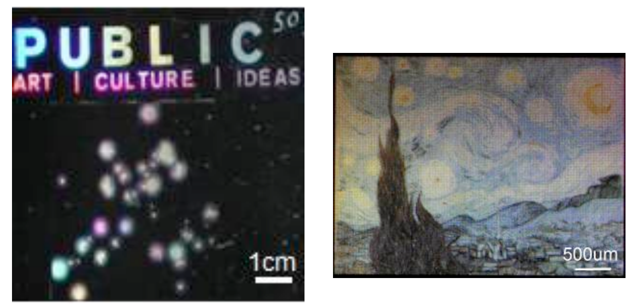

Figure 2: Nano-media produced using optical lithography techniques. a) Large-format sample produced for journal *PUBLIC* using photolithography. b) High resolution image produced using maskless laser photolithography technique.

Inkjet-printed nano-media

Nano-substrates can also be patterned using an inkjet printing technique to embed a color pattern. Our group introduced this concept for the first time at the IEEE NANO2015 conference [7]. Figure 3 shows the concepts and results of inkjet-printed nano-media on a nano-substrate composed of 1-D array of RGB pixel bands. High resolution inkjet printer, Fujifilm Dimatix DMP-2831 (with 1 pL cartridge installed), was implemented to print ink dots in the size of 20 um ~ 40 um on the nano-substrate. The printed dots cover specific pixel bands on the nano-substrate to selectively activate or deactivate pixels. Various visual colors are achieved by properly controlling the ink coverage ratio on the RGB pixels. For example, as shown in Figure 3(a), silver ink droplets were jetted into the shape of capital letter 'F' on top of the green bands of the nano-substrate so that only the green pixels were activated. The inset color image in Figure 3(a) shows the printed green color letter 'F'. Figure 3(b) shows the printed color pattern in the size of 2 cm × 1.5 cm. Figure 3(c) shows the unique optical variable effects of the printed sample.

Inkjet printing is in fact a very delicate technique and the quality of the inkjet-printed nano-media is determined by the nano-substrate pixel design, surface chemical properties, polymer material properties, ink material properties, fluidic dynamic properties of the ink droplets, temperature, and mechanical control accuracy.

Using this inkjet printing technique, color images and patterns with structural pixels can be printed according to any user-defined pattern and personalized information, which is very challenging, if not currently impossible, for conventional OVDs. Other types of functional components, such as interactive features or devices, can also be printed on nano-media following similar strategies and processes.

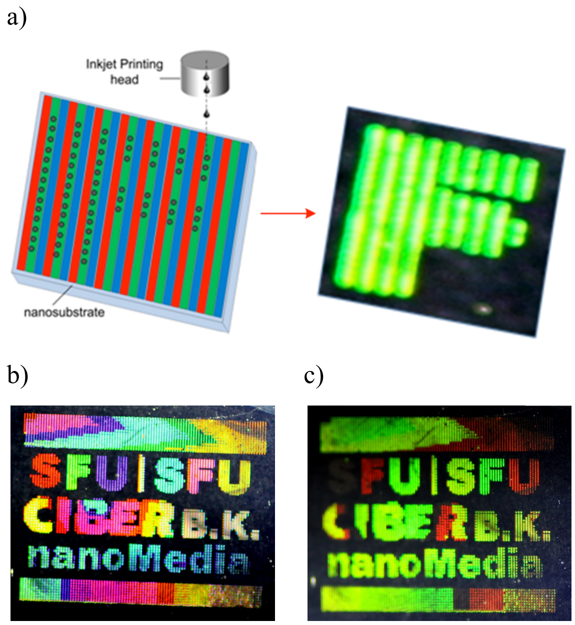

Figure 3: Nano-media produced using inkjet printing technique. a) Schematic of inkjet printing on nano-substrate to produce a green color letter 'F' and the photographic image of the printed green letter 'F'. Photographic image of the printed color patterns captured from b) the ideal viewing angle and c) a different angle.

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