WHITEPAPER

Nano-Optic Display Technology

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OVERVIEW

Nanotech's nano-optic display technology employs sub-wavelength nano-scale diffractive structures and proprietary algorithms to enable high impact visual designs, product authentication, and brand protection. The technology enables visual effects that include RGB true colour (24 bit), high-contrast movement, on/off effects, and image switches; all enabled using diffraction efficiencies approaching the theoretical maximum. Viewing angles up to 180 degrees along the horizontal axis and pixel resolutions up to 12,700 ppi have also been demonstrated. Electron beam lithography-based origination coupled with Nanotech's proprietary software algorithms result in an authentication solution that redefines the standard for holographic images. The features are compatible with current high-volume brand protection production, yields, and durability standards.

INTRODUCTION & BACKGROUND

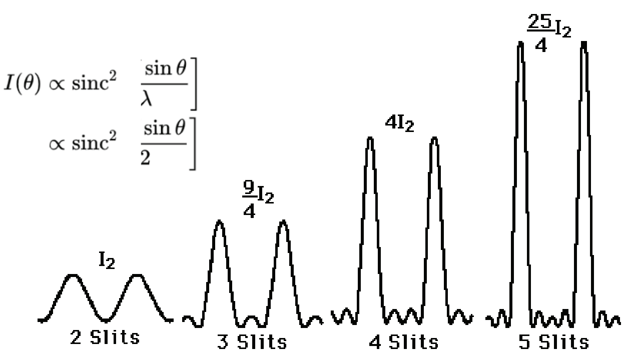
Recognizing that hologram technology was largely antiquated and did not offer sufficient differentiation to the observer or authenticator, Nanotech saw the need to develop a new advanced optical variable device (OVD) platform. Nanotech envisioned creating stunning structural colours through the interaction and manipulation of natural light with an array of nano-structures. The company envisioned a platform that would create a new paradigm shift in the technological advancement of visual brand protection features and all forms of document authentication.

This paper explores Nanotech's diffractive OVD technology based on nano-scale structures and their exceptional diffractive visual characteristics. This new technique for originating OVDs creates distinctive, highly visible colours that are much more discernable then current holographic micro-scale grating-based structures, especially in low-light environments. Nanotech produces sub-wavelength periodic nano-hole arrays with extraordinarily high efficiencies and resolutions approaching theoretical maximums for diffractive structures. These nanoscale structures have many advantages over traditional grating and lens-based optics, including low aspect ratios leading to more mechanically robust structures in thinner material layers.

Current state-of-the-art overt brand protection features found on most products rely on diffractionbased OVDs, which are largely holographic in nature. OVDs are traditionally considered to be difficult to produce because they are replicated from a master holographic shim that requires expensive, technologically advanced equipment. However, extensive use of holograms has lowered the cost of these specialized tools, compromising the security of these features in recent times. Diffraction gratings in the micrometer scale, which form most surface relief holographic features, are limited by small viewing angles and poor colour definition, as the grating diffracts all wavelengths of light within a few degrees of viewing. Volume holograms offer a partial solution to this problem by providing high optical efficiency and good definition of single colours however, they are more costly to produce, require thicker materials to be effective, and are limited to very small viewing angles making large images difficult to see.

The ideal brand protection OVD possesses multifaceted features that require complex processing to manufacture yet produce an intuitive and simple message to the authenticator. Incorporating multiple effects into a single OVD is desirable as it greatly increases the complexity to counterfeit the feature.

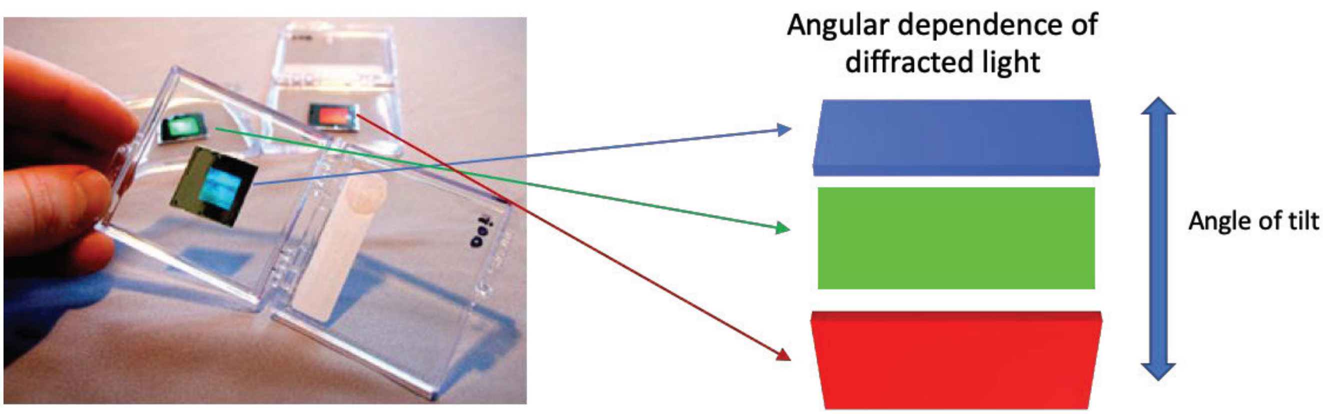
DIFFRATIVE NANOGRAPHIC TECHNOLOGY

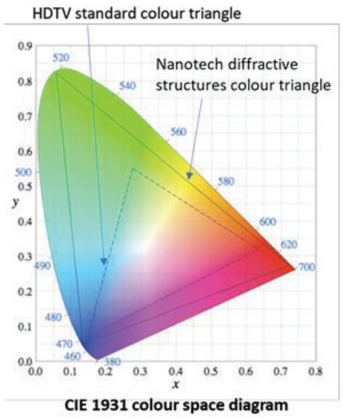


Fraunhofer Diffraction Intensity

Nano-optic diffractive structures are separated by a distance (the periodicity, or pitch) roughly on the same scale as a wavelength of light (~400nm to 700nm). These nano-structures split (diffract) different light waves into specific directions which depend on the periodic spacing. The intensity of the light waves reflected is related to the density and shape of these diffractive structures. Generally, the smaller the periodicity (the denser) the structures are, the higher the intensity of light. The relationship of diffractive structure size and periodicity to intensity is illustrated by the Fraunhofer Diffraction equation: intensity is proportional to the square of the amplitude – the more slits per area, the greater the intensity.

Diffractive colours are generally bright, pure RGB colours with high intensity, but are also highly angularly dependent. This angular dependence means that viewing a particular diffractive colour image requires positioning the image under a given light source and tilting it until the designed angle of diffraction (viewing) is found.





Nanotech's diffractive RGB CIE colour triangle vs. HDTV capability (top). Example of an actual Nanotech OVD demonstrating true colour image (bottom).

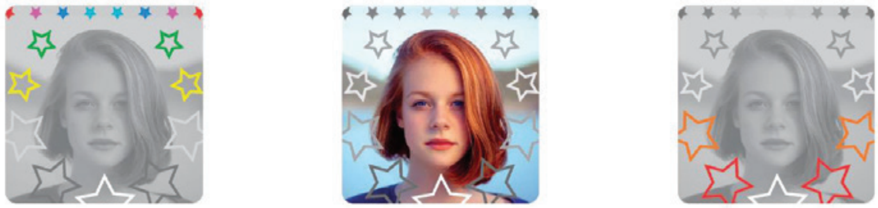
Diffractive structures can be blazed or non-blazed. Blazed structures provide the highest theoretical diffraction intensity for a specific wavelength of light at a specific "blazing angle". However, their nanoscale geometry is difficult to originate at large scales, and mass production of such structures requires a high fidelity process such as roll-to-roll UV casting that is still relatively uncommon in the holographic industry. The motivation to solve these issues is high as a combined blazed structure with nano-scale densities holds the potential to produce the ultimate diffractive technology.

Nanotech's blazed diffractive nano-structures exhibit true RGB colours for hyper-photorealistic image reproduction. True RGB means a wider and more flexible colour triangle in the CIE 1931 colour space diagram compared to active displays and other known diffractive technologies (see below). While this capability provides the platform with hyper-realistic image reproduction, it introduces design challenges. Images designed on current computer display technologies may appear different than the final output, for example, a slight over saturation in Photoshop may translate into a gross over saturation in the final image due to the ultra-high diffractive efficiency.

Nano-scale structures provide additional advances with respect to resolution. The lower bound of resolution in diffractive technology is determined by the size of a colour sub-pixel, red, green and blue, and should not be smaller than 2um x 2um. Below this limit, additional diffractive properties may be introduced to the image and induce unwanted rainbowing effects. The upper limit is mostly set by the resolution the human eye can detect, which for static images is approximately 40-50um, with most individuals not noticing pixels smaller than 80um. For multi-frame animations (e.g. "holographic movies") Nanotech has empirically validated that pixel sizes of up to 200um provide a "pixel-less" experience for the viewer.

Despite a large number of recent emerging technologies, superimposing multiple advanced features typically increases the thickness of the OVD and/or the number of materials required. This naturally leads to an increase in manufacturing complexity causing lower yield and higher cost. Nanotech's nanographic display technology transcends the aforementioned issues by imposing a number of novel combinatory features beyond typical single-function designs. At the most fundamental level, the sub-wavelength dimension of nano-scale structures enables high-intensity diffractive colours by leveraging maximum density and engineering blazing angles optimized for each wavelength of colour. The resulting pattern resolutions of up to 254,000 dpi (~100nm "dots"), while yielding potential pixel image resolutions as high as 12,700 ppi (2 pixels per micron). A single nano-scale layer of pixels cast or embossed into a substrate can be arranged to produce multiple overt effects such as motion, "ON/OFF" RGB image transitions, image switches, and ultrahigh definition true colour artwork.

Core to supporting the design and layout of nanographic OVDs, Nanotech developed proprietary software that utilizes advanced optical modeling for rapid simulation. Nanotech's OVD images showcase intense high-definition artwork, capturing deep colours including skin-tones via RGB-based true colour mixing and fluid motion effects. See exemplars in the figures below.



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Nano-scale diffraction structures provide much larger viewing angles as the spread of the first order diffractive vectors is larger, and therefore better colour definition for OVD features may be realized. This translates directly into a user experience which is both unique and more intuitive to perform. The fabrication of such small geometries poses many challenges, as the diffraction limit of light constrains standard photolithography to sizes larger than half of the wavelength of light in the visible spectrum (200nm to 400nm), which is much larger than Nanotech's nano-structures (~100nm – 200nm). Deep-UV systems face many barriers to produce the 100nm to 200nm geometries required, with projection and immersion lithography being too costly and impractical for brand protection OVD applications. A new class of direct-write based lithographic systems, such as electron-beam lithography (EBL), provide a method for constructing structures well below the diffraction limit, as small as 8nm or less[1, 2]. For OVD applications, these systems can be used to create originations or master shims for reproduction of nickel shim tooling and recombination necessary to manufacture these gratings at high volumes in the same manner as traditional surface relief holograms. Proper handling, substrate preparation, and subsequent processing of materials to be patterned in an EBL require specialized clean-room facilities and supporting equipment.

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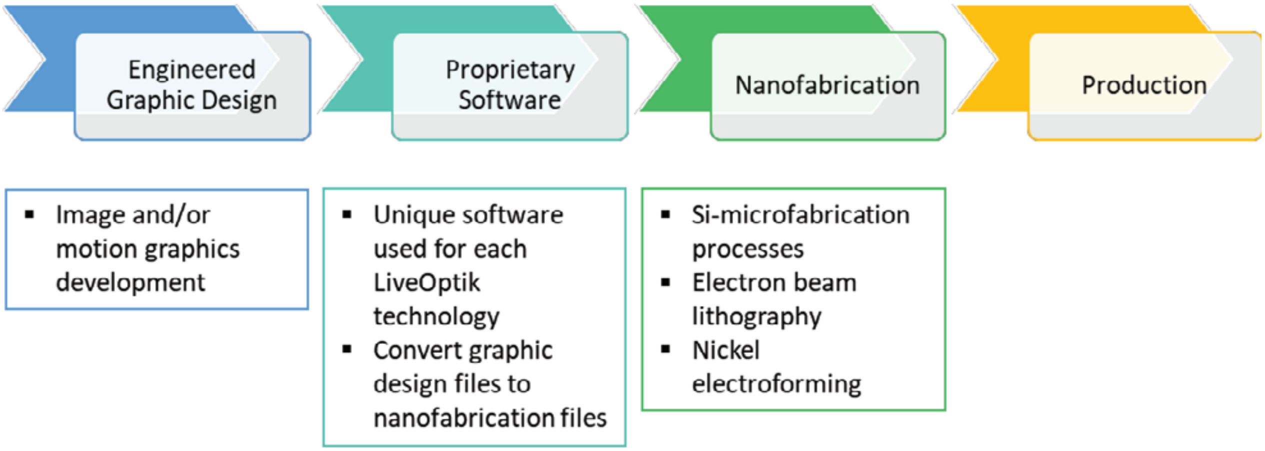
[1] *Leech P., "Pattern Replication in Polypropylene Films by Hot Embossing," Microelectronic Engineering 85 (2008) 181–186.*

[2] *Wilhelmi O., et al. "Rapid Prototyping of Nanostructure Materials with a Focused Ion Beam," Jpn J. Appl Phys. Vol. 47, No. 6 (2008), pp. 5010-5014.*

DEVELOPMENT PROCESS OVERVIEW

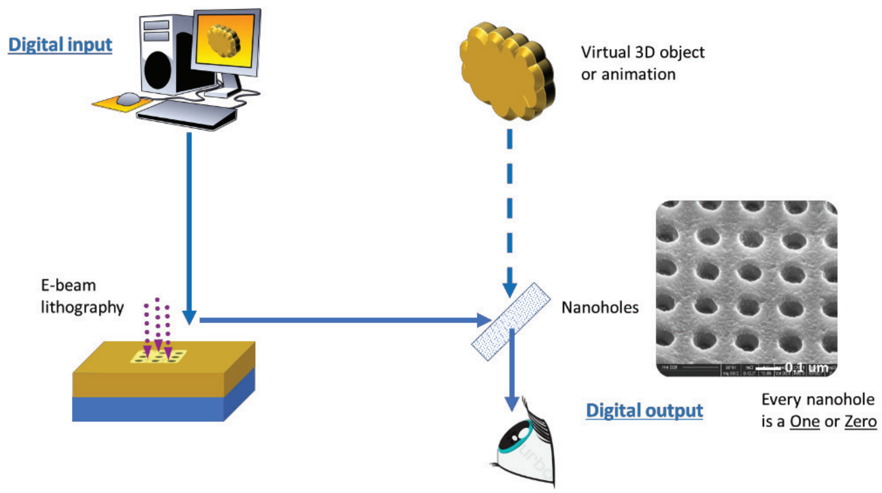
A customer's image concepts are brought to Nanotech's engineered graphic design, where an image is optimized for the nanographic display technology. Once an image is finalized, Nanotech's proprietary software is used to convert the graphic design files to nanofabrication files that can be used on Nanotech's EBL system . The ultra-stable 100kV EBL writes an image pattern anywhere from a few hours (typically) to up to several days, which is then used to fabricate a nickel shim through electroforming. This nickel shim is what is used to emboss or cast the final product.



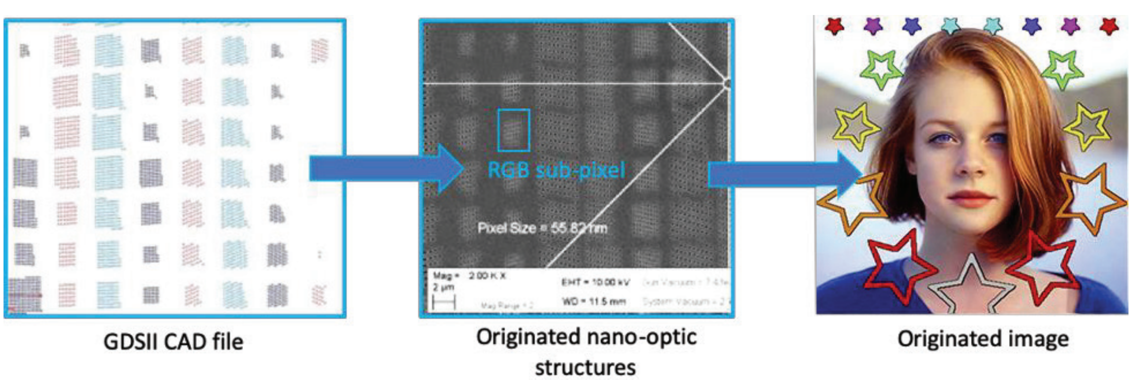
Nanotech production process

NANOTECH PROPRIETARY SOFTWARE

Nanotech's proprietary software is unique for each display technology. The software is used to convert a graphic design file (e.g. AI, After Effects, PS files, etc.) to nanofabrication files (e.g. GDSII) that can be read by Nanotech's EBL system. One major differentiator of Nanotech's software is the retention of all of the digital information in the graphic or animation outputted to the physical structural colour display device (the final product image). Every bit of data in each pixel of the image or animation is represented as a physical nano-structure on the final origination.



Integration of Nanotech proprietary software



Compete retention of digital information in the production of the final image

NANOFABRICATION OF NANOTECH ORIGINATIONS/MASTER SHIMS

01 EBL design file conversion

02 EBL write onto silicon wafer

03 Process silicon wafer for deposition

04 Seed layer deposition

05 Nickel electroforming

06 Wafer and shim separation and cleaning

EBL fabrication flow processing steps for Nanotech master shim originations

Nanofabrication techniques have been widely used in the semi-conductor industry for the last three decades to produce high volume and relatively low-cost devices. This industry utilizes step-and-repeat manufacturing flow and optical-based photolithography techniques to achieve uniform nano-scale features over large wafer areas. However, the tools designed for this process flow are primarily suited to silicon wafer handling and are not ideal as the throughput is not nearly adequate for roll-to-roll patterning of substrates. Furthermore, fabricating sub-wavelength features below the diffraction limit using optical-based techniques has proven very costly and limited to replication of the same shapes over and over[3]. For these reasons non-optical fabrication methods are required for the production of Nanotech OVDs. Non-optical manufacturing tools such as EBL and focused-ion beam lithography can be employed to create sub-wavelength structures in nearly any shape and pitch on wafer scale substrates. While these tools are not high-throughput systems suitable for the volumes required by the OVD industry, they can be used to create master shims for the subsequent high-volume manufacturing of nanographic features. Nanotech has created a new process for producing masters suitable for use in existing high-volume roll-to-roll thermal embossing or UV casting manufacturing processes.

Nanofabrication files are converted to EBL CAD files and the EBL system writes an image pattern onto a silicon wafer. This takes all the digital information contained in the nanofabrication files and constructs it into physical nano-structures on the wafer surface. The silicon wafer is processed to prepare it for the deposition of a seed layer. At this stage the structural colour display device has been yielded. Once the seed layer is deposited, the wafer undergoes nickel electroforming. The electroforming is done to transfer the device into a form (a nickel shim) that is suitably robust to survive casting/embossing of the final product (stripe, patch, label). The nickel shim (the master) is then separated and cleaned. It is now ready to cast or emboss the image onto a substrate.

[3] *Wiley B.J., Qin D., and Xia Y., "Nanofabrication at High Throughput and Low Cost," ACS Nano 2010 4 (7), 3554-3559.*

CONCLUSION

Nanotech's nanographic display technology employs nano-scale diffractive structures to create unique visual effects that include full RGB colour, on/off effects, and image switches. Sophisticated algorithms and modeling comprise Nanotech's propriety software and ensure that nano-scale structures are deployed in a manner that creates a visual experience characterized by exceptional brightness, enhanced viewing angles, and extreme high definition resolutions that far exceed the limits of human perception. The combination of nano-scale origination and sophisticated algorithms results in a product authentication solution that is virtually impossible to replicate or reverse-engineer. Given the global increase in counterfeiting goods, brands require new solutions to protect their brand and prove authenticity to their customers. Nanotech's new brand protection technology offers an innovative solution to brands looking for the next generation of Brand Protection.