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Designing Nano-Media Across Disciplines: Circular Genealogies and Collaborative Methodologies at the Optical Frontier

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Abstract

This paper draws on a collaboration between scientists, an artist, and a media researcher to produce 'nano-media,' a media surface designed at the nanoscale, to examine the interdisciplinary methodologies and circular genealogies of emerging media. Based on nano-optical structures and optical variable devices, the scientifically innovative technology uses many analog techniques to construct a new kind of material that can produce striking iridescent images and simultaneously store covert information. The first goal of this research was to use these novel optical nanostructures to create a cover for the periodical *PUBLIC*. This paper details the project as it moved from conceptual exploration to the prototype and manufacturing stages, considering the specific hurdles of translation between fields, the production challenges, and the points of intersection that brought the team together. By situating nano-media in 'retro' techniques of image production – including analog cinema and photography – the paper also provides a point of entry for artists and humanists to engage and participate in the imagination and innovation of media built at the nanoscale. Finally, through the lens of nano research, the paper challenges the 'art-sci' moniker to reflect a more fluid and multiple cross-pollination of fields as we design the media of the future.

Keywords

nano-optics, research-creation, art-science, interdisciplinarity, emerging media, nano-media, iridescence, biomimicry, media history, materiality

Introduction

After a full day of meetings discussing nano-media with various curators at Vancouver art galleries, I was crossing the street when a car I had not noticed zipped by me. I jumped back as a man turned my way and said with a chuckle, "What we can't see can't hurt us!" An innocuous statement to be sure, but after spending the week immersed in the world of nano-optics, my mind was attuned to questions of sight and visibility, not to mention the overarching ethical labyrinths of working in the realm of nanotechnology, and I could not help but pause to consider his words. Technologies of the nano, after all, are built at scales invisible to the unassisted human eye, and indeed it remains to be seen if being able to access matter at this scale is boom or bust for humanity. [1] The reason I was in town was an interdisciplinary collaboration in which as a media researcher, I brought together a team of engineers from the Ciber Lab at Simon Fraser University under the helm of Professor Bozena Kaminska,[1] together with the artist Christine Davis,[2] to develop a new kind of media surface and visual experience that combined the optical properties of materials at the nanoscale, the distinct methodology of nano-fabrication, and classical analog photography/cinematic techniques. We called it 'nano-media.'

In the world of nanotechnology, material structures and functional systems are built at the scale of nanometers, or billionths of a meter. Operating at this scale, nanotechnology "dreams of engineering every aspect of our material reality, precisely fashioned and designed at the limits of fabrication, one atom at a time." [2] Specifically, "the radical innovation" of nanotechnology (and nanoscience) is the ability to examine the properties of matter at the nanoscale, where "surface phenomena rather than mass properties govern the chemical and biological behavior of objects," meaning that, once we reach the nanoscale, materials have different properties – chemical, electric, magnetic, mechanical, and optical – than those of bulk materials. [3]

Colin Milburn has described the visualization of the molecular landscape as "nanovision," which is made possible through powerful scanning probe instruments like the scanning tunneling microscope (STM), scanning electron microscope (SEM), or atomic force microscope (AFM), that sense, feel, and map the atoms of the surface to create topographical images based on the data gathered through the "haptic encounter" of the scanning process. [4] Much of what has been called nano-art so far has been engaged with the nanosurface through these kinds of images, renderings, or (re)presentations, which provide ways to understand the invisible dimensions and scales of the nanoworld by using the sense of touch to explore the joined concepts of scale and surface. [5] This 'vision,' made possible through touch and tactility, is an example of nanotechnology research as "fundamentally an aesthetic endeavor in that it depends upon the production of new sensory experienc-

[1] The scientific team included postdoctoral fellow Dr. Hao Jiang, graduate students Reza Qarehbaghi and Mohamad Rezaei, and undergraduate student Mohammad Naghshineh.
[2] http://www.christinedavis.com

es" in which "the appearance of new kinds of vision and visual metaphors was key." [6][3]

While the STEM disciplines have taken to nano by storm, every day yielding new discoveries with the potential for radical change, there has so far been little access for those outside of the sciences to respond and engage with these developments in sustained and informed ways.[4] The aesthetic of the surface is in many ways an entry point for humanists and artists into nanotechnology, as it renders the nano visible and thus accessible. So far, however, there has been limited attention paid in the arts to the particular optical experiences that can be created using nanomaterials,[5] and the building of the surface, the making of materials that use the knowledge of nanovision, has been largely restricted to scientists, with some notable exceptions, such as Frederik de Wilde's *Hostage* (2010), Julian Melchiorri's *Cocoon* (2014), or Kimsooja's *Needle Woman: Galaxy was a Memory, Earth is a Souvenir* (2014). Indeed, artists and media scholarship – a field that should be most intrigued by the creation of new kinds of surfaces – have so far engaged rather tentatively with these new matters and their distinctive properties as materials and media. It is with this in mind that I formed an interdisciplinary team to creatively explore nano research and innovation of surfaces, specifically in the realm of nano-optics. The goal of our collaboration was not to access the surfaces of nature, to touch or image existing materials, but to in fact build a surface, one that would use the properties of materials and light as they interact at the nanoscale. We imagined a new kind of interface, a medium that would harness our ability to manipulate and design matter at the nanoscale to create novel visual experiences.

Driving the collaboration was an inquiry into the emerging possibilities of nano-optics that combined new scientific discoveries, experimental research and practical considerations, and the methodologies, questions, and particular knowledge (historical, material, aesthetic) of the artist and media researcher. As a first step in the partnership we decided to produce a cover for the fiftieth issue of the Canadian periodical *PUBLIC Art/Culture/Ideas*,[6] which was to launch on November 26, 2014 at the Art Gallery of Ontario in Toronto. The deadline for the project was therefore firm. What follows is an account of this first project, including scientific breakthroughs, practical challenges, and exploratory reflections on the methodologies and genealogies that emerged in the collaborative making of nanomedia.

Morpho Butterflies and Nano-Optics

The technology of nano-optics, or the field that is concerned with the properties of materials and light at the nanoscale, has so far been predominantly applied in the domains of security and authentication. One oft-referenced inspiration in this field is the blue morpho butterfly, whose wings appear blue to the human eye even though they contain no pigment and are transparent. This effect is due to the way the light diffracts from billions of nano-sized structures that constitute the wing. [7] (Fig. 1a) A number of natural organisms, from butterflies to beetles and minerals, have such iridescent properties, and scientists have been working to emulate them through the design of optical nanostructures, called optical variable devices (OVDs). These do not use color inks or dyes but, like the morpho butterfly, generate structural color through the light defraction from nano-sized slits or holes in a given material, such as a polymer or metal. (Fig. 1b) These can be very specifically designed to produce particular ultra-high resolution iridescent visual effects. [8] B. Kaminska and the Ciber Lab had been developing groundbreaking OVDs for a number of years already, including creating OVD nanoimages embedded and reproduced in a variety of polymers, for use in banknotes, for example. [9] (Fig. 2a) This technology was commercialized, and the lab was moving forward with new ideas to further improve their designs as well as their fabrication and manufacturing methods. They were also looking for new applications outside of the realm of security.

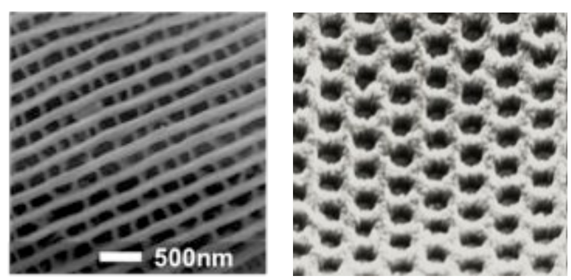

Figure 1a (left). Scanning electron microscope (SEM) image of morpho butterfly wing; Figure 1b (right). SEM image of nano-OVD produced by the Ciber Lab, also 500nm.

Independently of this, Davis too had been inspired by the properties of the morpho butterfly's wings. In her project *Who's Afraid of Red, Yellow, and Blue* (2008), she projected filtered light onto its wings to display not the familiar iridescent blue, but distinct color patterns. (Fig. 2b) The wings became a projection screen, a display of Davis' longstanding attention to the material properties of the projection process, experimenting with the materiality

[3] Victoria Vesna and James Gimzewski's *Blue Morph* (2007–), for example, is one such pioneering work that used the AFM and SEM to record sounds and images of an organic surface (wings of the morpho butterfly) to produce new aesthetic and sensory encounters with the nanoscale. http://artsci.ucla.edu/BlueMorph/

[4] This can be in part be attributed to the complexity of the technology, the speed at which it is developing, as well as the difficulty in gaining access to the newest developments. Experts in nano-optics (and particularly OVDs), for example, which are currently predominantly used for security applications, are reluctant to make their knowledge open to the public.

[5] For examples see Paul Thomas, Chapter 4, "Matter, Measurement and Light" in *Nano Art*, pp. 87–104.

[6] Christine Davis is the co-founder of *PUBLIC* and I am the current Managing Editor. See: http://www.publicjournal.ca/

Figure 2a (left). Nanostructures (OVDs) by the Ciber Lab; Figure 2b (right). Davis' *Who's Afraid of Red, Yellow, and Blue*.

and haptic nature of the screen, and developing interactions between projected light and organic surfaces to produce modulated images. In *Who's Afraid*, the slide projected is a close up of a Wonder Bread package, echoing a relationship between biomimicry and evolution.

The scientists' primary goal was to create new nanostructures with increasingly better colors and manufacturing processes. They strived to produce larger and customizable images, to reduce cost in the production methods, and to improve resolution and storage capabilities. Davis meanwhile was intrigued by the ultra-precise manipulability of light and the way colors were generated, by the brightly iridescent properties of the OVDs, and the possibility of integrating pixels of OVDs in a variety of materials and art contexts. Though coming from entirely different disciplines, the common interest in playing with light and color through the manipulation of materials rooted the project in a shared curiosity and placed the emphasis on process and research. Together we wondered how media innovation would take shape in the context of such interdisciplinary inquiry.

The Science of Nano-Media

Nano-media is the next step in nano-OVD innovation produced by the scientists in our team. [10] It is built by combining a pixelated pre-fabricated nanosubstrate with an image. The image is located in the intensity control layer (ICL), which can be produced either through photochemical exposure, laser writing, or as a black-and-white photomask that is then precisely aligned with, or imprinted on, the substrate. The nanosubstrate and ICL together produce a colored image. (Fig. 3) The scientists early on compared this superimposition of two layers to the early twentieth century process of Dufay color film, which used color filters based on a regular mesh of red, blue, and green lines on the film base, along with black-and-white photographic emulsion, to produce color images. In nano-media the film becomes a nanosubstrate, but the principle remains the same. One can say that nano-media brings together biomimicry (through the 'imitation' of the morpho butterfly) and 'retro' – analog, material – techniques of image production (such as those of Dufay color film).

The substrate is made up of nano-sized holes (nano-hole arrays, or NHAs) or slits/graves, that create pixels, with approximately one billion holes in a square centi-

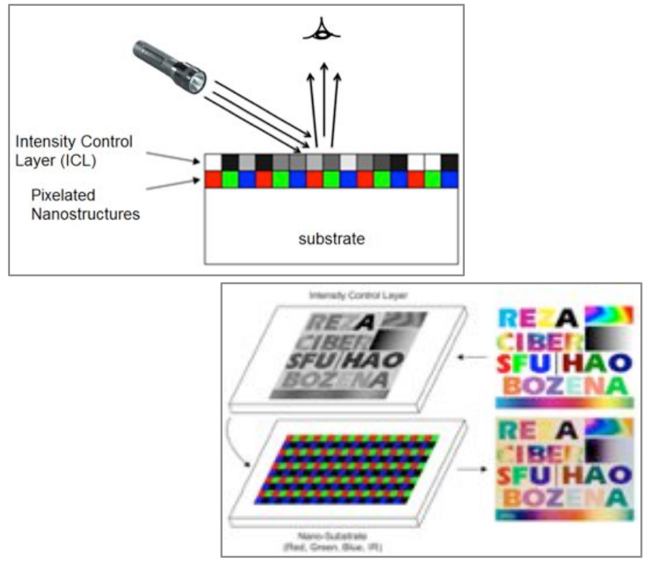

Figure 3. Diagrams of ICL creation and alignment on nano-substrate to create a nano-media.

meter of nanosubstrate. Each pixel is made of four sub-pixels: R (red), G (green), B (blue), and IR (infrared), with the dimensions of each pixel changing depending on the production method, and thus producing different color resolutions. (Fig. 4a) Depending on the pixel size, nano-media can produce images ranging from 1,270 pixels-per-inch (PPI) to 12,700 PPI. This is equivalent to a range between 36,830 dots-per-inch (DPI) to 368,300 DPI. The smaller the sub-pixels the higher the resolution. [11]

The substrate material fabricated with pixels is built using nano-fabrication tools like focused ion beam lithography (FIB) and e-beam lithography (EBL). It can be made with a variety of materials, including metals, polymers, paper, tissue/fabric, or glass. Nano-holes with a thin layer of metal (ex. gold, silver) in particular produce an extraordinary optical transmission (EOT) and display intense visual colors across the visible spectrum. [12] These are referred to as plasmonics, and are used in OVDs, sensing, and other areas.

The RGB pixels can be tuned to produce any color with the ICL, while the IR pixel is used for non-visible information (storage). There are a number of techniques to produce the ICL, which can offer different resolutions

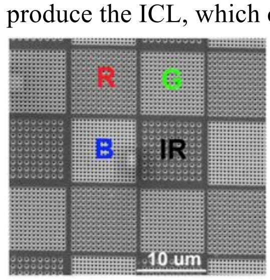

Figure 4a (left). SEM image of the fabricated nanosubstrate showing the structure of the sub-pixels; Figure 4b (right). The first prototype of an ultra-high resolution color image stored on nanosubstrate, with 36,830 DPI (2 x 1.5cm).

when combined with the appropriate pre-fabricated substrate. The final resolution of nano-media therefore depends on both the sub-pixel size and the ICL. High resolution can be achieved through a photochemical method, while lower resolution can be achieved using a photomask. In the photochemical process, a silver halide emulsion is exposed, or the ICL is written, for example using a laser. Using a photomask, a 'negative' of the image is produced and then aligned with, or imprinted on, the nanosubstrate. In both cases the technology functions much like photography, and the team initially described the technology as nano-photography, or nanography. Ongoing comparisons to analog versus digital methods became increasingly apparent and useful in the collaboration (more on this below), and the scientific team continues to explore new ways that analog methods can be adopted for the development of nano-optical materials and surfaces.

For a long time there have been limitations with using nano-optical structures, such as the need to generate a costly stamp for each (very small) image (a stamp is a 'form' made of nanostructures embedded with an image that is used for high volume reproduction), and this is reflected in the kinds of applications that use them, such as banknotes. [9][10] Indeed, while the visual quality of nano-images is continuously improved, [13] there had not yet been a solution for fabricating images without the use of stamps, limiting the expansion of the technology.

With the *PUBLIC* project in mind, the scientific team developed the techniques of nano-media, producing image prototypes of around 2 x 2cm. (Fig. 4b) The elimination of the stamp meant that larger images could be made more easily: rather than building each image from nanostructures to make a stamp, the image was now located on the ICL and 'transferred' to the pre-fabricated nanosubstrate. Moreover, the development of the substrate to include the IR sub-pixel meant that these nano-optical structures could concurrently store a variety of information into the visible image on the various layers of the infrared spectrum (digital binary information, a bar code, a 2D QR code, a grey-scale image, etc.). The result, nano-media, was an extremely thin 'film' that could both display and store a variety of information, and could be produced incomparably faster to the stamp-only methods. [11] The question to be resolved was how to transfer the process used for the prototype to the production of 1,000 issues in a period of roughly eight months.

Collaboration and the Evolution of an Idea

Davis and I, both based in Toronto, travelled to Vancouver in April and August 2014. We did preparatory research on nano-optics and on the work produced by the lab, which was sent to us in advance. A few things quickly became apparent:

1. The Analog, the Material

In considering the production of nano-media, we pinpointed early on numerous analogies to analog processes: Dufay color film's two-layered process, photography's use of emulsions, exposures, and negatives, as well as physical methods of printing like lithography and mezzotinting. This ongoing return to analog techniques was a way for us, the non-scientists, to access the innovations of nano-optics and nano-media. Moreover, Davis' background as an analog photographer, her knowledge of emulsions, and of photographic processes in general, proved helpful to the engineering team, who was unaccustomed with working in this increasingly obsolete 'mode.' This, alongside her experience working across media, armed her with much more practical and material understanding than the scientists expected, which laid the foundation for a fruitful collaboration. While the scientists were searching the world for emulsions, Davis' familiarity with, for example, DIY methods, showed the scientists a new way of approaching the problem, not as scientists, but as an artist searching for, if not making, her materials.

Understanding nano-media in a set of development and fabrication processes allows us to contextualize it as material and therefore to situate it within a larger media history. First, the physicality of the holes in the substrate is not unlike that of early computing technologies, where punched cards or microforms, for instance, carried data through a system of holes.[7] The difference, broadly, is in the size of the holes and material used. Then there is the nano-media itself, a foil-like material that, when produced in large quantities through a roll-to-roll manufacturing industrial process, has a materiality akin to film. Giuliana Bruno describes film as a kind of surface, "a thin skin, a membrane," and, writing about Tacita Dean's film *Kodak* (2006), makes an observation, about the making of celluloid film, that resonates equally with 'nano-film,' as "intimately dependent on being touched and transformed by light, in time, and taking time." [14]. The concept of the surface as a way of thinking across media becomes increasingly useful with nano materials. As Silvia Casini notes, when "we discuss visibility and invisibility…we cannot avoid talking about the surface." [15]

Turning to analog practices provided more than useful analogies, as nano-media itself can be understood as a digital-analog hybrid technology. While it is digital in the design of the substrate structures and ICL, the analog techniques, such as that of exposure, the ability to 'transfer' or 'imprint' any analog image directly into a substrate (i.e., without converting it to a digital file), as well as the physical material of the foil, open the door to interesting connections that cast a light on the circular genealogies of visual media and information technologies. This ability to draw on the history of materials and processes is helpful not only for humanists entering the realm of nano research, but for finding commonality across disciplines.

[7] I presented a paper on this topic, "Nanotechnology, Media Studies, and the Punched Card," at the Canadian Communication Association conference at Brock University in 2014.

2. Innovation and the Disruptive Experience

Nano-media has the unique capacity to store covert information in the IR layer. Though it is one of its defining features, we quickly discovered the challenges of applying it in the *PUBLIC* project. While some were practical (we had a short timeframe and were already working with so much that was new), there was also a conceptual difficulty surrounding the user experience. How do we show the ability to store data in nano-media in a way that the viewer could *experience* as something different, unfamiliar, and novel? We eventually decided against the idea of using a reader (e.g., smartphone) to scan the information since, without being given any explanation, a user would not engage with this technology any differently than scanning a QR code or using an AR application. In other words, as soon as the reader was introduced and the data had to be read, decoded, and viewed on a separate screen, the very fact that the information was stored in the material (hardware) and not the software would be difficult to convey, and probably lost. Moreover, we decided that convincing *PUBLIC*'s readers to download a new application would be difficult, not to mention the additional work of producing the software (work for which we would have to find a specialist outside of the current team). Some ideas we had to resolve this issue included: using filters that would show the data stored in the IR layer; encoding the data only in certain sections of the cover; encoding different data on different sets of covers; integrating the data with pressure or biomedical sensors; storing sound which could be played though the cover. While these challenges could be solved in an installation or exhibition setting – for example with special lighting conditions that used filters that would allow access to the IR – they were unrealistic in the *PUBLIC* project. We could not, with our time and budgets constraints, find an appropriate design and manufacturing solution that would create a disruption of user experience. After weeks of deliberation, we decided that though it was a feature that should be showcased, we would proceed for the cover without IR data storage. This was a very unexpected outcome for the scientific team, an example of the aesthetic and media experience taking precedence over the 'scientific method.'[8]

3. "In my world"; Optics Across Fields

Interdisciplinary collaborations, especially across the arts, humanities, and sciences, have long been described as a meeting of, and translation between, cultures. [16] Currents in transdisciplinary collaborations mostly focus on the coming together of arts and sciences, but technologies, argued Cornelius Borck, act as the "communicating vessels," an idea that shifts the notion of fields from distinct to overlapping. Indeed, the binary moniker 'art-sci' proves all the more insufficient as collaborations work towards new kinds of technologies and emerging materials, surfaces, and media. It is a false dichotomy that produces an illusion of clarity that neatly, if only in terminology, joins two 'worlds' when worlds are messy and many. In the diverse context of nano research, which itself blurs the lines between science and technology by bringing together, among others, biologists, chemists, physicists, and engineers, [17] it is not enough to speak only of a meeting between 'art' and 'science.' While Borck locates technology as "the communicator, the missing link and material linkage between art and science," [18] Robert Root-Bernstein also adds media as one such often overlooked communicator. In his integral tetrahedron model – what he describes as the "universe of innovation" – he brings together sciences, technologies, media, and aesthetics, to describe the "pathways between arts and sciences" as "two-way streets mediated by media and aesthetics." [19] He does not here articulate how he differentiates between science and technology, and technology and media, which are particularly muddled categories in the field of nano research. However, his point about the influence of media and aesthetics back onto science and technology is significant: new technologies that explicitly work to converge our materialities, the matter of the world, into information and into media [20] generate new aesthetics, but, conversely, new aesthetic approaches must also influence the materials (media, technologies) produced. For this, the spaces of scientific and technological innovation need a sustained rapport with the knowledge and methodologies of the arts and humanities, allowing 'art-sci' to better reflect the fluid and varied cross-pollination of fields possible in transdisciplinary research.

In this particular project, searching for points of contact between our fields resulted in exploratory conversations that often began with, "In my world…." In the earliest stages, the very scale of the nano at which the scientists were working seemed "incomprehensible" [21] to Davis and I, a feeling that, as Victoria Vesna and James Gimzewski have put it, "our minds short circuit" when confronting the scale of nanotechnology. [22] To get a better sense of working at this scale, we toured the sterile environment of the clean room where the scientists worked. The meticulously regulated process of suiting up was like a confirmation into another, usually inaccessible to us, 'world,' and the affective experience gave us an entirely different outlook on the physically demanding labor of working at this scale.

There were a few unexpected hurdles of translation, some larger than others. For example, the realization that while the artist was using DPI as a measurement for resolution, the scientists were using PPI. While these were the standards in their fields, calculating the conversion and understanding their relationship, though relatively straightforward, was a crucial step in making sure everyone was visualizing the same level of resolution. Another such example arose with color. While Davis would be giving the scientists an image file produced through Ado-

[8] See Robert Root-Bernstein's argument that scientists must "abandon our reliance on a 'scientific method'" to embrace the kinds of knowledge that come from the artist. In "Aesthetics, Media, Sciences, and Technologies," 276.

be Illustrator, the scientists would convert this using an in-house software to produce the ICL. But how does color translate from the Adobe software to nano-media? Put differently, how does the structural color produced through nano-media, translate into that of a software like Illustrator? Here the scientists had to familiarize themselves with the artist's tools, while she had to make sense of the software they were using. While color systems like RGB, CMYK (cyan-magenta-yellow-black), and HSL (hue, saturation, lightness) have been established for pigment-based color printing, "color systems have not been established for plasmonic-based color." [23] Slowly we understood how to produce the best colors through the different stages of production, allowing Davis to better imagine the final nano-media result of her Adobe file.

From Craft to Automation

Over the course of the summer, the scientists faced one seemingly insurmountable hurdle after another, each step of the process to scale up the fabrication a challenge. In effect, they were scaling up a technology extremely rapidly, moving from the prototype stage to the production of 1,000+ copies, along with their integration into the publishing process, in just a few months. All the while they continued to develop new ideas, working to find solutions and alternative approaches to unforeseen problems. For example, if using an alignment method, the substrate and ICL had to be juxtaposed with an accuracy of 5 microns but current available machines could only do it at 100 microns. A misalignment of that scale, because we are dealing with nano-sized structures, would ruin the entire visual effect. So, while the scientists proved this could be done by hand, producing very high-resolution images (Fig. 5), the labor-intensive nature of the work made it impossible to do for so many copies.

As for any scaling-up endeavor, the challenge was in how to transfer the innovations of a manual process to one that was automated, in moving something akin to craft, to an industrial set-up using sheet-to-sheet or roll-to-roll fabrication. The biggest challenges were the production of the ICL and deciding how the image would be produced: through photochemical exposure, laser writing, or the alignment or imprinting of a photomask, each of which has particular advantages and restrictions.

Figure 5. Nano-media image (3 x 5cm) produced by manual alignment.

At the start of the project, guided by the 'scientific method,' we had been aiming to achieve the highest possible resolution, and thus strived to develop the ICL using the photochemical process. The scientific team went on an international search for the right materials, emulsions and lasers. Concurrently, to be on the safe side, they kept refining the photomask approach with different resolutions, using different polymers, coatings, bonding layers, and alignment methods. Finally, by September, with just over two months remaining, it was decided we had to use the relatively reliable photomask imprinting technique, as the time and labor involved for the other more innovative processes were above-and-beyond our capacities for this project, and also too risky.

For Davis this was not a significant change of plan, as the resolution using the photomask was still incredibly high. Whereas for her the 'less advanced' method was perfectly suitable for the purposes of the *PUBLIC* project, the scientists' were not used to thinking of their technologies in this way, where a 'less optimal' solution was perhaps better and sufficient. For this project, where the goal was not just a technological showcase but also an aesthetic exploration, we could work with 'less.'

Once this decision was made, we proceeded with as much testing as possible before ordering the final roll of nano-media foil (the combined nanosubstrate and ICL) from ITW Covid.[9] In one such test, when a metalized polymer on a sample *PUBLIC* cover produced problematic results, the decision was quickly made to change to a transparent foil. Even if the visual effect would be diminished (since there would be no metal to enhance the color's brightness), it could be superimposed on top of a cover, and in those places where there was no image the foil would simply be see-through, rather than opaque due to the metal. Time was running out.

Designing the Cover

By early fall it was also time to make a final decision on the cover image. Alongside the ongoing scientific progress, Davis had continuously been looking for ways to play with the themes of (in)visibility, perception, nature, light, and color. With the assistance of fellow artist Scott Lyall,[10] and as the theme of this *PUBLIC* issue was *The Retreat* (based on a visual arts residency at the Banff Centre), they produced an image of a dark and shadowy forest. This would be the cover printed on paper with inks as per usual. Based on the decision to go with the mask method, Davis would superimpose this printed layer with sections of nano-media, an array of sparkling iridescent colors emanating from the cover. The light structures would flicker from the forest and also retreat, a reflection on the hidden depths of nature and the moments of illumination that shine from he darkness of invisibility or the unknown. (Fig. 6)

[9] A professional company that became an essential collaborator.
[10] As well as her assistants Polina Teif and Vlad Lunin.

Figure 6. Test of final design of the cover with nano-media manually superimposed.

Armed with a design plan, the scientific team proceeded to design the necessary nano-media components and sending them to ITW for roll-to-roll fabrication.

Troubles at the 11th Hour

From the start we followed the instruction from *PUBLIC's* printer, located in Québec, who indicated the kind of paper and lamination usually used. We had decided that it would be best to print the cover and assemble it with the nano-media layer in Vancouver, before shipping the ready-to-bind product to our Québec printer, who would print the interior of the issue as usual. Their soft deadline for receiving the cover was November 1. After receiving the nano-media foils from ITW, and with a bundle of printed test covers, the team set out to a lamination company in Vancouver. While some lamination tests had been done before this stage to ensure that covering the foil wouldn't dampen the effects too drastically, a last minute decision to coat the foil in an extra reflexive coating (to compensate for the switch from metal to transparent foil), was not tested, and the result, when everything was put together – cover, nano-media foil, lamination – fell flat. The light reflected too much from the entire surface, while the specific colors of the image were not easy to distinguish, dampened drastically by lamination. It was now November 3, 23 days before the *PUBLIC* launch.

The next few days were frenzied. We enlisted the help of *PUBLIC*'s designer and printer to help us find a solution and salvage the hundreds of meters of foil. After much deliberation, we opted to put the foil inside the journal as a rectangular insert with a round cut out where the foil could be placed. In a true spirit of teamwork, the entire Vancouver team set up a production assembly line to produce the inserts, which were delivered to Québec on November 20. (Fig. 7a) Davis and Lyall produced a revised cover that included the image of what the nano-media would have been. They printed a 'shadow' of the nano-media, with the solid ink functioning as a 'fixing' of the variable optical version within. A special shipment of

Figure 7a (top). Assembly of nano-media insert; Figure 7b (bottom). Final results in *PUBLIC.* [11]

the issue with nano-media insert included, arrived in Toronto on Nov. 24, two days before the to launch. (Fig. 7b)

Outcomes, Debrief, and Next Steps

The project did not turn out the way it was initially conceived, with difficulties in scaling up the nano-media prototype, with all of its features, and the last minute move from the cover to an insert. But, since artistic and scientific projects face similar challenges as they move from speculation to production, the team navigated the difficulties with flexibility and creativity. In hindsight, under the circumstances of the firm deadline, our goals were set too ambitiously. But the collaboration was still successful in developing interdisciplinary methodologies for technological exploration, research, and innovation. Moreover, the furious pace of the project lead to numerous innovations, which, though they could not be incorporated into *PUBLIC,* have already produced new patent applications [24] and partnerships, and are the foundations for new ideas and ongoing research.

Continuing their collaboration, the team is now working on an installation for Davis, exploring the possibilities of thread embedded with nano-media pixels, drawing on the histories of weaving and looms. The entirely different conditions of the installation allow for a process that can develop organically through singular objects, leaving time for technological and aesthetic exploration through trials, feedback, and observation. The possibilities for nano-media are vast, and if we give artists and humanists access to these technologies, we might start seeing things very differently.

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[11] The final product in motion: https://vimeo.com/112849671

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