Nondestructive, ultra-high-resolution patterning of light emitters for immersive virtual-reality displays

Principal Investigator
Himchan Cho

Department
Materials Science and Engineering

Co-Investigators
Seongkyu Maeng, Sun Jae Park, Jaehwan Lee, Hyungdoh Lee, Jonghui Choi, Jeung Ku Kang

Hompage
http://ngonlab.com

For augmented/virtual reality (AR/VR) near-eye displays, high-resolution pixel patterns are essential for achieving superior image quality. However, the fabrication of high-resolution pixel patterns with quantum dots or perovskite nanocrystals is challenging due to the susceptibility of the luminescence properties of nanocrystals to degrade during the patterning process. The research team led by Professor Himchan Cho of the Department of Materials Science and Engineering has successfully addressed this challenge by exploiting the photocatalytic properties of these light emitters. The research team designed a materials and patterning process that facilitates crosslinking reactions between surface ligands of nanocrystals based on the photocatalytic properties of nanocrystals upon ultraviolet light exposure. As a result, the team managed to achieve uniform high-resolution pixel patterns (corresponding to ~12,000 ppi) while completely preserving the intrinsic optical characteristics of the light emitters. This study provides a simple way to realize immersive high-resolution near-eye displays based on quantum dot and perovskite emitters. In recognition of this feat, the research paper was published in the August issue of Science Advances (Volume 9, Issue 33).

Background

Following the COVID-19 era, society is rapidly starting to enter the metaverse. Big U.S. tech companies like Microsoft, Meta, and Apple are launching augmented reality (AR) and virtual reality (VR) devices with the aim of capturing this emerging market. According to MarketsandMarkets, the AR/VR market related to the metaverse is expected to reach $1.5 trillion by 2030, and the related display market is also projected to experience rapid expansion. Hence, in response to this demand, it is imperative to implement advanced display technologies to increase Korea's presence in the display market. Ultra-realistic AR/VR near-eye displays for the metaverse require two key features: high resolutions and high color purity. From a materials perspective, the need for emissive nanomaterials with high color purity is evident, while from a process perspective, there is an urgent requirement for the development of high-resolution patterning techniques. However, there remain limitations in terms of the technology necessary to fabricate uniform, ultra-high-resolution patterns while preserving the favorable inherent optical properties of emissive nanomaterials, especially for solution-processable light emitters such as colloidal quantum dots and perovskite nanocrystals. Prof. Himchan Cho's research team developed a new method to overcome this challenge.

Description

The research team led by Prof. Himchan Cho designed a novel patterning process named "direct photocatalytic patterning," which utilizes the strong photocatalytic properties of perovskite nanocrystals. The high photocatalytic activity of perovskites facilitates crosslinking reactions between ligands of nanocrystals and crosslinker molecules under light exposure. Unlike previous studies that required both a crosslinkable additive and a photoinitiator, this study takes advantage of the photocatalytic properties of nanomaterials themselves, enabling pattern fabrication with minimal ultraviolet (UV) light exposure. The additive also compensates for surface defects that often degrade optical properties during UV exposure and processing, leading to an increase in luminescence efficiency. The team successfully fabricated uniform ultra-high-resolution (~12,000 pixels per inch, ppi) perovskite nanocrystal patterns with pattern widths as small as 560 nm. This resolution far exceeds resolutions typically required for AR/VR displays. This technology is not only applicable to perovskite nanocrystals, but also to II-VI, III-V semiconductor quantum dots and light-emitting polymers, demonstrating its versatility and industrial applicability. The team also proved the feasibility of applying this process in consecutive multilayer processes as well as to the fabrication of light-emitting diodes.

Implications

This direct photocatalytic patterning technique preserves the optical properties of various emissive nanomaterials through a simple process while enabling the fabrication of ultra-high-resolution patterns. This aspect is expected to be beneficial in a wide range of industries, including displays and image sensors, opening up prospects for the practical application of the developed process in these fields.

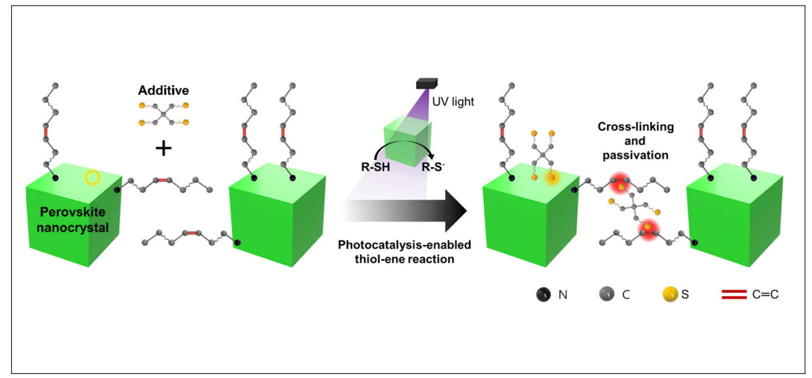

Figure 1. Schematic diagram of the direct photocatalytic patterning process.

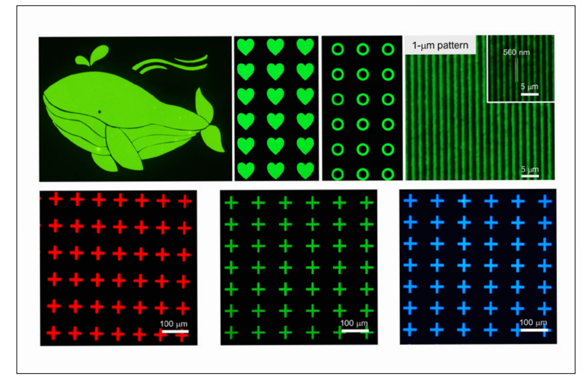

Figure 2. Optical microscope images of perovskite nanocrystal (PeNC) patterns fabricated via the direct photocatalytic patterning process.

Research outcomes

Science Advances, 2023, 9, eadi6950 (featured image of issue 33)

1 patent application (Film patterning method and electroluminescent device and display device including a patterned film, Republic of Korea)

12 related articles (including The Korea Herald "High-Resolution Virtual Reality Implementation...KAIST Develops Patterning Technology", Donga Science "[Reading Science] Korea's Display in Crisis...Maintaining a Gap with New Technology")

2 awards (Excellent Poster Award (The Korean Ceramic Society), Excellent Paper Presentation (The Polymer Society of Korea))

Research funding

Samsung Electronics - 2nd generation of KAIST semiconductor research grant (IO220810-01911-01).

National Research Foundation of Korea (NRF) grants (2022M3H4A1A03085346, 2022M3H4A1A03076626, and 2022M3H4A1A04096482).

Wearable Platform Materials Technology Center (WMC) funded by the NRF grant (NRF- 2022R1A5A6000846)