3D printing of quantum dot embedded polymer nanowires for patterning to triangular-delta and Bayer

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Abstract. This contribution presents a method for producing nanoscale color pixels for high-resolution displays using 3D printing of vertically freestanding nanostructures containing red, green, or blue light-emitting quantum dots (QDs). Traditional methods for producing pixels suffer from decreased brightness and pixel density at higher densities due to the reduced volume, but our 3D printing method allows for individual control of brightness by adjusting pixel height in 3D, resulting in a two-fold increase in brightness without changing lateral dimensions. We demonstrate sub-micrometer pixels representing primary colors at a super-high density, enabling image patterns with a pixel resolution of 8,400 ppi and individual modulation of sub-pixels with a possible pixel resolution of 5,600 ppi in triangular-delta and Bayer type designs. The method can be applied to displays, information storage, cryptography, and image sensors. The 3D printing method is a versatile approach for photonic research and has potential for contributing to the development of a range of applications.

Introduction

The demand for high-resolution display technologies has increased rapidly in recent years. Current technologies, such as liquid crystal displays and organic light-emitting diodes, have limitations in terms of pixel resolution, color gamut, and manufacturing cost. In this work, we present a novel method for producing high-resolution 3D color nanopixels using quantum dot (QD)-embedded nanophotonic inks. Our method utilizes femtoliter liquid-ink-based 3D printing technology, which enables the production of nanoscale cross-sections with high aspect ratios and heights of up to 10 µm. The resulting nanopixels can be used for a wide range of applications, including displays, information storage, cryptography, and image sensors.

Methods

We prepared the QD-embedded nanophotonic inks by dispersing CdSe/ZnS QD powder for red (650 nm), green (540 nm), and ZnCdSe/ZnS QD powder for blue (480 nm) in three xylene solvents (concentration: 5 mg/mL). We then dissolved polystyrene powder in xylene solvent (concentration: 0.2 wt%) and diluted each QD solution in three polystyrene solutions, targeting 20 wt% of the QD to the dissolved polystyrene. After sonication for 5 min, we obtained the nanophotonic inks.

We used a femtoliter liquid-ink-based 3D printing method to produce the QD-embedded nanophotonic inks. This method enabled the production of 3D color pixels with high-aspect-ratio nanoscale cross-sections, having heights of up to 10 µm that can be varied to enhance or control the brightness of the pixels.

To characterize the optical properties of the nanopixels, we used an LED light with a wavelength of 365 nm and a continuous-wave laser light with a wavelength of 405 nm for QD excitation. The LED or laser light was illuminated from the backside of an objective lens using a dichroic mirror. PL emissions from the nanopixels were collected by the same objective lens and split into two parts, one directed to the color CCD camera for imaging the spatial distribution of the signal and the other to the spectrometer used for analyzing the wavelength-dependent intensity.

Fig. 1. 3D printed quantum dot embedded nanowires of dot-matrix, triangular delta, and Bayer pattern designs with a glass nanocapillary nozzle for the printing
Results and Discussion

We demonstrated the production of R, G, and B light-emitting nanopixels based on the 3D printing of QD-embedded nanophotonic inks. The resulting nanopixels had high aspect ratios and heights of up to 10 µm, which can be varied to enhance or control the brightness of the pixels. We demonstrated image patterns with a pixel resolution of 8,400 ppi and individual modulation of sub-pixels with a possible pixel resolution of 5,600 ppi in a triangular delta-type and Bayer pattern designs. The 3D designs of the nanopixels enabled brightness control but did not induce significant changes in the spatial resolution. The presented method has several advantages over existing technologies. The femtoliter liquid-ink-based 3D printing method enables the production of 3D color pixels with high aspect ratios and heights of up to 10 µm. The resulting nanopixels can achieve high resolution and color gamut, making them suitable for use in a wide range of applications. However, additional efforts are required to address the challenges associated with industrial-level manufacturing, such as parallelization with multi-aperture nozzles and delicate quality control of the substrates and nozzles. The presented method can realize super-high-resolution arrays of light-emitting materials for displays, information storage, cryptography, and image sensors.

Conclusion

To summarize, our study showcases the successful production of red, green, and blue light-emitting nanopixels through the 3D printing of QD-embedded nanophotonic inks. Femtoliter liquid-ink based 3D printing allowed for the creation of high-aspect-ratio 3D color pixels with nanoscale cross-sections reaching heights of up to 10 µm, providing greater control over the brightness of the pixels. The potential applications for this method include the creation of super high-resolution arrays of light-emitting materials for use in displays, information storage, cryptography, image sensors, and more. As we move towards device-level implementation, there may be challenges to overcome, such as addressing the lead time associated with 3D printing methods. To this end, we suggest exploring parallelization techniques utilizing multi-aperture nozzles. Additionally, ensuring the quality control of the substrates and nozzles will be necessary for reliable, industrial-level manufacturing. Enclosure within a transparent polymer matrix may also help enhance the mechanical stability of the high-aspect-ratio nanopixels.

References