The Role of Metasurfaces in Future Display Technologies

Mark L. Brongersma

brongersma@stanford.edu
Geballe Laboratory for Advanced Materials, 476 Lomita Mall, Stanford University, CA 94025, USA
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ABSTRACT

Nanostructured films termed metasurfaces are finding their way into display technologies where they can reduce power consumption and facilitate new levels of control over the spectral, angular, and polarization properties of light emission. I will discuss the basic optical properties of metasurfaces and illustrate their use in future display technologies.

1. Introduction

In optics, we traditionally control and measure the behavior of light using bulky optical components. The field of metasurface optics aims to manipulate the flow of light with more compact, planar optical elements and we are currently seeing an explosion of research on this topic. Research in this area started with the development of diffractive optical elements in the 1970s and it came with the exciting promise to reduce the size and weight of complex optical systems [1]. With the emergence of the field of nanophotonics, we have now learned how to control the flow of light at the nanoscale with the help of semiconductor [2] and metallic [3] nanostructures. This naturally led to the development of optical metasurfaces that are comprised of dense arrays of nanostructures that can be created by a variety of thin film deposition and patterning techniques. These can serve as essentially flat optical elements that can deliver very high-numerical aperture optics [4], [5], meaningful integration with conventional optics [6], minimal aberrations [7]–[10], multiple functions in the same physical space [11]–[14], strong non-linear effects [15], [16], holograms [17]–[20], and new levels of control over the light field [21]–[23]. Metasurfaces are now also starting to be integrated into optoelectronic devices, for dynamic beamsteering [24], solar energy harvesting [25] and in displays [26]. Here, we discuss opportunities for the use of metasurfaces in organic light emitting diode (OLED) displays.

2. Metasurface for OLED displays.

In a recent collaboration between Samsung Advanced Institute of Technology, Stanford University, and Hanyang University, we have demonstrated that the architecture of OLED displays can completely be reenvisioned through the introduction of nanopatterned metasurface mirrors [26]. The opportunity arose as solid state light emitters rely on the use of metallic contacts with a high sheet-conductivity for effective charge injection. Unfortunately, the surface of metal contacts can also guide light in the form of surface plasmon polaritons (SPPs). A notable fraction of the light emission in OLEDs typically couples to SPPs and this leads to unwanted dissipation of optical energy into the metal. This can severely limit the external quantum efficiency. A number of years back, our group illustrated how metallic electrodes can be nanopatterned in such a way that the excitation of SPPs is prevented across the visible spectrum, while facilitating a desirable Lambertian emission profile [27], [28].

A second opportunity for patterning metallic electrodes arises from the fact that OLED architectures are typically set up to take full advantage of beneficial microcavity effects. In OLEDs, Fabry-Pérot (FP) cavities are employed to minimize the undesired coupling of emitted photons to waveguided modes and to narrow the intrinsic emission spectrum of the emitting organics by capitalizing on the Purcell effect. Often at least one of the mirrors in a FP cavity is metallic. By patterning that mirror, we can modify the reflection phase for light. Whereas a regular, metallic mirror provides a fixed reflection phase near 180^o, a judiciously nanopatterning mirror can provide any desired reflection phase [26], [27]. For this reason, the resonance frequency of a cavity with a nanopatterned, metasurface mirror can be decoupled from the physical cavity length. As a result, red (R), green (G) and blue (B) cavities can be made with the same mirror spacing. This can provide major processing advantages for displays where RGB pixels sit next to each other.

We have shown how highly-efficient color pixels can be created by spatially varying the nanopattern designs on an electrode and without a need for color filters. The new META-OLED architecture facilitates the creation of devices at the ultra-high pixel densities (>10,000 PPI) required in emerging display applications (e.g. augmented reality) using scalable nanoimprint lithography. The fabricated pixels also offer twice the luminescence efficiency and superior color purity as compared to standard color-filtered white-OLEDs.

3. Conclusions

Metasurfaces can offer tremendous control over light emission processes. The can naturally be incorporated in a wide variety of devices using scalable and inexpensive fabrication techniques, including nanoimprint lithography. We have illustrated how it may be possible to incorporate metasurface technologies in future META-OLED displays.

4. References

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