Grating-patterned Perovskite Light Emitting Diodes for Enhanced Performance

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Abstract: We introduce grating patterns into perovskite films using a simple soft lithography method with common DVD discs as templates. The patterned perovskite films exhibit enhanced photoluminescence and the performance of light emitting diodes is improved.
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1. Introduction

Organic-inorganic hybrid perovskites have attracted much attention due to their excellent optoelectronic properties including strong optical absorption, ultralong carrier diffusion length, and high photoluminescence quantum yield. Recently, they have been widely applied for high-performance optoelectronic devices like solar cells, light emitting diodes (LEDs) and photodetectors. In all these fields, patterning perovskite films at nanoscale can help improve device performance.[1] For light emission applications, nanoscale patterns can enhance the outcoupling efficiency and affect the angular and spectral emission profiles. However, perovskites are fully dissolved in most polar solvents, which make it incompatible with conventional photolithography and electron beam lithography. A variety of soft-lithography approaches has been developed recently to directly pattern perovskite films. In this abstract, we adopt the solvent-assisted gel printing (SAGP) method developed by Jeong et.al.[2] and create functional patterns into perovskite films using conventional DVD discs as templates. This simple and facile strategy provides large area grating nanostructures and reduces the fabrication cost. The grating-imprinted perovskite films exhibit enhanced photoluminescence (PL) and faster PL decay compared to unpatterned ones. In addition, the grating-structured perovskite LED shows 5-fold improvement of external quantum efficiency (EQE).

2. Results and discussion

Conventional DVD-R discs are used as the initial masters. A razor was used carefully to separate the DVD-R into two parts, the polycarbonate substrate without metal label was used and cleaned with ethanol to wash off the organic dye layer. The poly(dimethylsiloxane) PDMS solution (Sylgard 184 silicone elastomer kit) mixed with curing agent (volume 10:1) was poured over the grating side of the polycarbonate substrate. After curing at 80ºC for 3 hours, the PDMS mold was carefully peeled off and used as the imprint mold in the SAGP process later.

The LED device structure consists of indium tin oxide (ITO)/PEDOT:PSS/perovskite/TPBI/LiF/Ag. The perovskite material used here is quasi-2D perovskite $(PEA)_2(MABr)_{n-1}Pb_nBr_{2n}$ with n=5.[3] In step I, the quasi-2D perovskite dissolved in DMSO solution (30% weight) was spin-coated onto the ITO/PEDOT:PSS stack at 3000 rpm for 30s. Due to the high boiling point of DMSO solution, there was still a small amount of residual solvent after 30s spin. The wet film is imprinted immediately with the prepared PDMS mold and gradient annealed from 40 ºC to 80 ºC for 20 minutes (step II). A mediate pressure was added on top of the PDMS mold using a mechanical press clamp during the annealing process. After the DMSO solution evaporated, the PDMS mold was slowly peeled off (step III). The grating-imprinted structure was then transferred to a thermal evaporator for evaporating TPBI (40 nm), LiF (1 nm) and Ag (100 nm) in sequence. The optical image of the grating-imprinted perovskite film displays multiple colors due to light diffraction as shown in figure 1(a). The scanning electron microscope (SEM) and atomic force microscope (AFM) images both exhibit clear periodic grating structures (figure 1(b) and 1(c)). We extract the height profile and plot it in figure 1(d). The perovskite grating structure has a 750 nm period and 500 nm line width. The element map measured by X-ray energy dispersive (EDS) technique is shown in figure 1(e). Br, Pb, C and N are distributed with the grating pattern, further confirming the uniformity of the perovskite grating pattern.

The PL spectra of the patterned and planar perovskite films on glass are present in figure 2(a). The PL intensity of the patterned film is enhanced up to 2.5 times; however, no apparent difference is observed in the PL spectrum shape and peak wavelength of both films. We also performed the transient PL decay measurement, the results are shown in figure 2(b). The decay rate of perovskite grating is faster than that of the planar perovskite film, which indicates enhanced spontaneous emission rate due to Purcell effect.

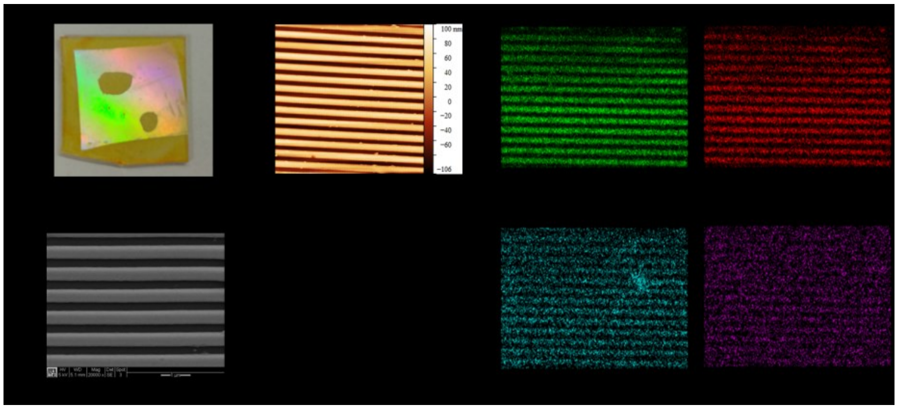

Fig. 1. Surface morphology characterization of grating-imprinted perovskite films. (a) The optical image of the grating-patterned perovskite film. (b) SEM and (c) AFM image. (d) The height profile along a vertical line in (c). (e) The distribution map of elements in the perovskite film.

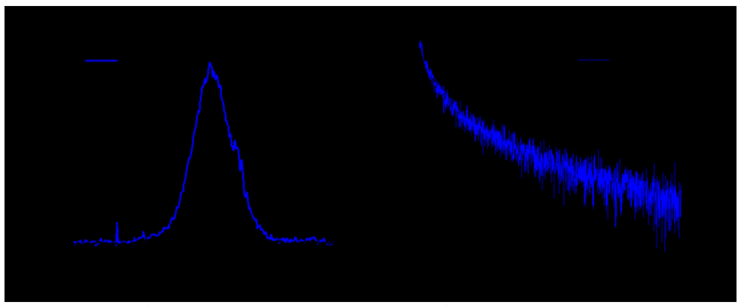

Fig. 2. (a) The PL spectra and (b) transient PL intensity decay of grating-imprinted and planar perovskite films.

The energy band diagram of the imprinted perovskite LED is shown in figure 3(a). The electrons and holes transport to the perovskite layer and are confined by PEDOT:PSS and TPBI layers due to the energy barriers. The recombination rate is enhanced due to coupling with the grating structure. We plot the luminance and EQE as a function of applied voltages for both imprinted and planar perovskite LEDs in figure 3(b) and 3(c). The max luminance of the imprinted perovskite LED is ~2 times as high as that of the planar one. Furthermore, the EQE of perovskite LED is improved from 0.02% to 1% with the aid of the imprinted grating structure. Therefore, this work demonstrates a facile way to improve the efficiency of perovskite LEDs through nanoimprint.

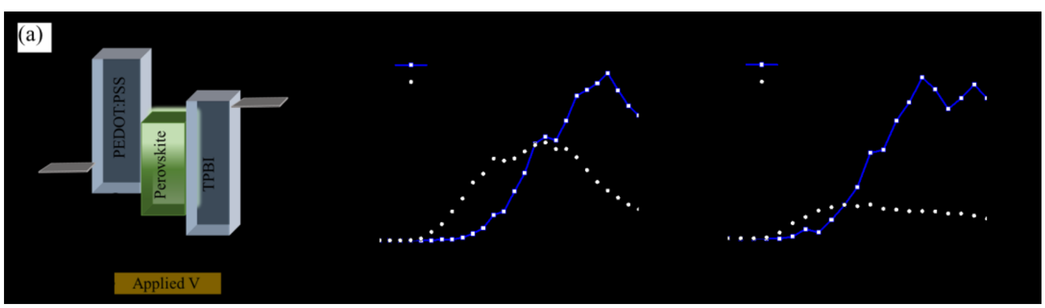

Fig 3. (a) The energy band diagram of our perovskite LED structure. (b) Luminance and (c) EQE as a function of applied voltage for grating-imprinted and planar perovskite LEDs.

3. References

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