A Laser-Illuminated Microdisplay for AR

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Abstract

We present a novel photonic integrated circuit (PIC)-based laser display architecture that enables compact and efficient augmented reality (AR) light engines. By integrating a thin, front-lit PIC illuminator directly onto a liquid-crystal-on-silicon (LCoS) panel, we achieve significant reduction in size, volume, and lateral footprint compared to traditional LCoS light engines.

Author Keywords

AR (Augmented Reality); LCoS (Liquid-Crystal-on-Silicon); Photonic integrated circuit (PIC); Front-lit illumination; Laser display.

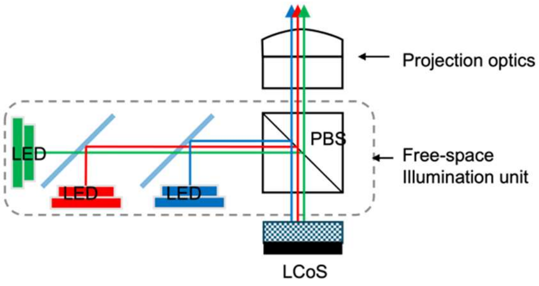
1. Introduction

LCoS (Liquid-Crystal-on-Silicon) is a non-emissive micro-display technology that has been adopted in several off-the-shelf AR (Augmented Reality) devices [1]. Compared to other AR light engine solutions, LCoS offers the advantages of technological maturity and relatively low cost. However, one of the biggest limitations of current LCoS light engines is their large form factor, primarily due to their reliance on bulky free-space illumination modules. These modules not only add to the overall size and weight of the system but also increase manufacturing complexity and cost. To overcome these challenges, we propose a laser-illuminated micro-display architecture that integrates a thin, front-lit photonic integrated circuit (PIC) illuminator directly onto the LCoS panel. This innovation eliminates the need for bulky illumination modules, simplifying the optical design and significantly reducing the size, volume, and lateral footprint of the light engine, enabling a compact and lightweight solution for AR applications. Additionally, the use of laser illumination enhances brightness, color performance [2], and supports a wide field of view, addressing key performance requirements for next-generation AR devices.

Figure 1 compares a conventional LCoS projector based on free-space illumination optics (Figure 1a) with our proposed compact light engine architecture using PIC illumination (Figure 1b). In the conventional design, a bulky polarizing beam splitter (PBS) is required to combine the illumination and imaging paths, adding significant size, weight, and cost to the system. Additional collimation optics, beam-shaping elements, and dichroic mirrors are used to collect and combine red, green, and blue light, as well as controlling the light's spatial and angular characteristics, further increasing the form factor and assembly complexity.

In contrast, Figure 1b illustrates our proposed light engine architecture, which rethinks the illumination module by leveraging a photonic integrated circuit (PIC) [3-5]. The PIC eliminates the need for bulky free-space optical components by integrating the core optical functions—light collimation, beam expansion, color mixing, and polarization control—directly onto a single chip. This on-chip approach replaces collimating lenses, dichroic mirrors, beam-shaping elements, and the PBS, dramatically reducing the size and complexity of the light engine. The PIC illumination layer can be directly bonded to the top of the LCoS without stringent alignment requirements. This integration also simplifies the lens stack design, creating a configuration similar to that of emissive displays and further minimizing the overall footprint and weight.

(a) Conventional LCoS projector



(b) PIC frontlit LCoS projector

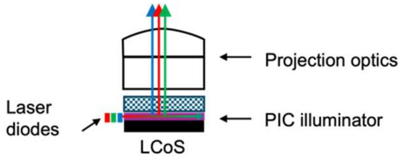


Figure 1. Schematics of (a) conventional LCoS projectors; and (b) our proposed PIC front-lit LCoS projectors.

2. Display architecture

Figure 2a shows the schematic of the proposed display stack, where a PIC device is directly bonded to an off-the-shelf LCoS cover glass with a polarizer film laminated on top of the PIC device for image formation. The main function of the PIC is to provide highly polarized and uniform illumination to the LCoS. Figure 2b shows a top-view schematic of the PIC device. PICs operate in the single-mode regime – light is confined and guided in single-mode ridge waveguides (RWGs). This enables precise control over the propagation of light in-plane and thus the spatial uniformity, as well as the characteristics of light emission out-of-plane, such as polarization, dispersion, chief ray angle (CRA), emission cone angle, far-field beam profile, etc.

The PIC circuitry can be divided into the beam expansion region and the emission region. In the expansion region, cascaded Y-splitters are used to split the input light into a waveguide array. The Y-splitters are optimized using an inverse design method to ensure

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low insertion loss across a broad bandwidth, encompassing the entire visible spectrum, and good tolerance against waveguide thickness and critical dimension variation.

Following the light splitting, an array of coarse-wavelength multiplexers (CWMs) is employed to separate white light into R, G, B colors. In principle, this design can support both color sequential displays (i.e., temporal multiplexing of RGB channels) and displays with RGB subpixels (i.e., spatial multiplexing of RGB channels). Here, we choose to use a color sequential LCoS to achieve higher resolution. For display operation, the R, G, and B lasers are turned on sequentially in synchronization with the LCoS color frame transition.

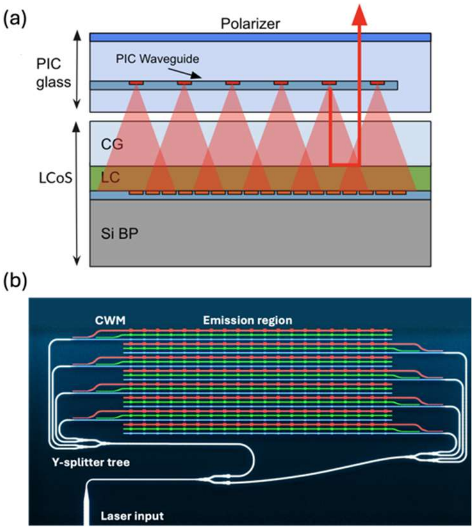


Figure 2. (a) Schematic of the proposed display stack. (b) Schematic of the PIC circuit.

In the emission region, light is extracted by arrays of pixelated grating couplers as it propagates along the ridge waveguides. We use pixelated grating outcouplers instead of continuous gratings to achieve a finite emission cone angle, matched to the f-number of the collimation lens, which is dictated by the required display field of view (FOV), panel size, and projector pupil size. The output light is designed to be highly polarized by using single-mode waveguides and polarization-selective gratings.

To ensure good spatial uniformity, we introduce a novel optical circuitry design — spatial interleaving of waveguide circuits. As illustrated in Figure 2b, light is split on-chip and fed from opposite directions via two sets of Y-splitters. This creates a compensatory effect, maintaining uniform illumination despite the monotonic decay in each direction.

Finally, due to the reflective nature of the LCoS, light will pass through the PIC again after being modulated and reflected by the LCoS panel. This puts another requirement on the PIC device - it must be highly transparent to avoid any ghosting or display quality degradation. We achieve this through layer stack optimization, resulting in a ghost level of less than 0.8% across the spectrum of interest, meeting the system specification.

3. Result

The assembled PIC-laser display is shown in Figure 3a. We first characterized the uniformity of the PIC illuminator before integrating it with the LCoS (Figure 3b). The emission area measures 6mm by 4mm, with the long axis along the ridge waveguides. Due to interleaved light propagation, the illumination is brighter towards the left and right edges and dimmer towards the center. The measured minimum over maximum intensity ratio is 71%, slightly lower than the simulated value of 80% due to layer thickness variation. We achieved good color uniformity with $\Delta u'v' < 0.01$ and an illumination contrast of over 250:1 at NA~0.2, consistent with simulation results.

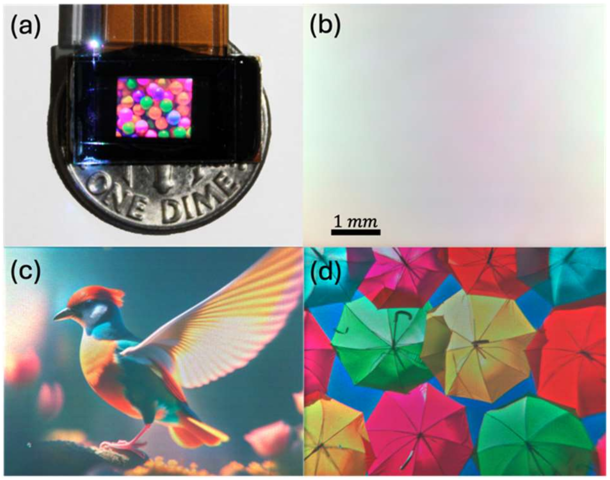
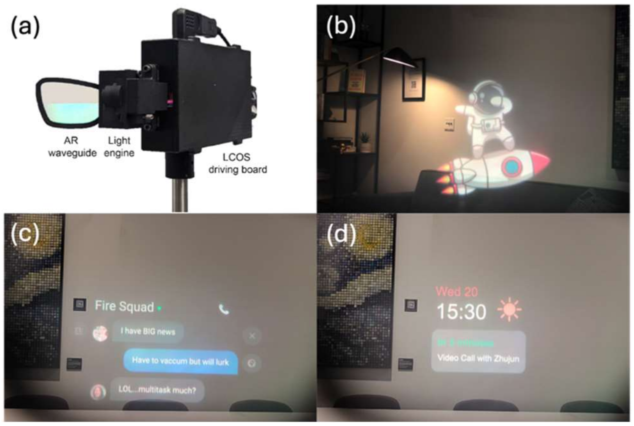


Figure 3. (a) The assembled flat panel laser display shown on top of a dime coin. (b) Measured uniformity map of a fabricated PIC device. (c-d) Measured display images.

The display performance under direct view is shown in Figure 3c-3d. An eyepiece is used to magnify the displayed image. The assembled display sequential contrast is around 40:1, significantly lower than the illumination PER. This is limited both by the LCoS panel contrast, and the alignment error between the PIC, LCoS and the polarizer film which was done manually for this demonstration. Laser speckles are visible as granular patterns in the image, resulting from interference between different PIC emitters on the LCoS plane. These can be mitigated using techniques such as wavelength or polarization diversity, dynamic diffusers, and microlens arrays.



Fire Squad

I have BIG news

Have to vaccum but will lurk

LOL...multitask much?

Wed 20

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Video Call with Zhujun

Figure 4. (a) Photo of the handheld AR setup. (b-d) Images captured through the AR setup.

Finally, we demonstrate the PIC-laser display performance at a system level by pairing it with an off-the-shelf pupil-replicating geometrical AR glass (Fig. 4a). The current demonstration is a handheld AR setup with the projector supporting 50 deg diagonal FoV. The volume mainly comes from the large off-the-shelf LCoS display driving board, and can be miniaturized significantly with a customized driver. With better integration and packaging, the light engine size can be reduced to under 1 cubic centimeter. Several types of AR use cases are demonstrated. We demonstrated various AR use cases, including mixed reality experiences (Figure 4b) and instant messaging and notifications (Fig. 4c-d).

4. Discussion

The current demonstration uses an off-the-shelf LCoS panel for rapid prototyping. In the future, more advanced integration with various display types can be pursued. For example, the PIC can replace the cover glass of the LCoS device, adding zero thickness to the display module. The PIC illuminator also offers unique opportunities when integrated with advanced LCoS panels with ultra-small pixel pitches (e.g. below 2 μm), such as Ferroelectric Liquid Crystal on Silicon (FLCoS) [6]. FLCoS promises higher resolution, faster response time and further size reduction. However, they require a higher source brightness, unattainable by LEDs but can be supported by the proposed PIC illuminator. In addition to LCoSs, the PICs can also be integrated with LCDs with RGB subpixels. Our calculation shows that by using PIC illuminators we can boost the optical efficiency by 10X over conventional LCDs by eliminating the need for lossy polarizers, diffusers and color filters in the display stack. More broadly, the PIC illuminator can serve as an enabling platform, unlocking opportunities for a range of new display technologies, including slim-panel holographic displays [7], pupil-steered displays [8], high-efficiency pancake lenses [9], and many more, opening up a realm of possibilities.

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