Toward Speckle-free Laser Engines on Chip for Augmented Reality Displays

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Laser beam scanning (LBS) is currently one of the most compact solutions for augmented reality (AR) displays. State-of-the-art LBS displays still rely on laser modules with three separately mounted red, green and blue (RGB) lasers and (miniaturized) free-space optics to combine the separate laser beams.

Leveraging recent advances in visible-light photonic platforms based on Silicon Nitride (SiN) and maturing heterogeneous integration technologies, we propose an integrated RGB laser engine on a single photonic integrated circuit (PIC).

This integrated solution not only reduces the size of the laser module, but also allows us to use external modulation to reduce the temporal coherence of the laser light. This high coherence of laser light often results in unwanted interference, causing speckle noise in the image. Additionally, we explore an alternative approach to mitigate this unwanted speckle effect: by integrating multiple laser sources in parallel, we can average out the speckle induced by each laser, but also increase the display's resolution and field of view (FOV).

1. Introduction

Future Augmented Reality (AR) displays need to have a higher brightness, larger field of view (FoV) and finer resolution, yet also need to be lightweight and consume less power [1]. To achieve these goals, improvements in both the light engine as well as the optical combiner are needed. The former is more and more realized using efficient, compact lasers diodes. Light engine architectures based on liquid-crystal-on-silicon (LCoS), digital micromirror devices (DMD), or laser beam scanning (LBS) with micro-electromechanical systems (MEMS) technologies all need compact and bright external light sources [2]. This is offered by the very compact semiconductor lasers (< 1 cc) with a high luminous efficiency (> 40 lm/W).

However, a major concern with laser light is the unwanted interference pattern, or speckle. When a scattering surface is illuminated with a strong coherent light source like a laser, a granular image is produced. The speckle contrast, i.e. the contrast between constructive and destructive interfering spots, needs to be reduced to 4% or less to be undistinguishable by the human eye [2].

Several techniques have been developed to reduce the speckle of a laser by leveraging wavelength, spatial, angular and/or polarization diversity. Some of these systems leave the laser source untouched and try to incorporate a mechanically moving element like a spinning diffusor or rotating half wave plate. Others try to widen the laser spectrum, i.e.

reducing the temporal coherence, by modifying the semiconductor structure fundamentally [3] or by relying on the laser dynamics and a corresponding driving scheme to broaden the spectrum [4].

Thanks to the maturing of photonic integration platforms for visible wavelengths such as silicon nitride (SiN) [5] and recent advances in heterogeneous integration techniques like micro-transfer printing (µTP) [6], we believe that more complex systems can be integrated together. This opens up possibilities for the dense integration of augmented reality light engines. Moreover, such a complex photonic system can then include speckle-reducing circuitry and components that do not rely on mechanical or bulky speckle-reducing techniques, but rather leverage mature modulation techniques borrowed from silicon photonic PICs in datacom and telecom. A similar system has recently been demonstrated with three laser diodes being flip chipped onto a SiN photonic integrated circuit (PIC) with a surface area of only 50 mm² [7]. This already goes beyond state-of-the-art commercial RGB laser engines that rely on miniaturized free-space color combiners [8].

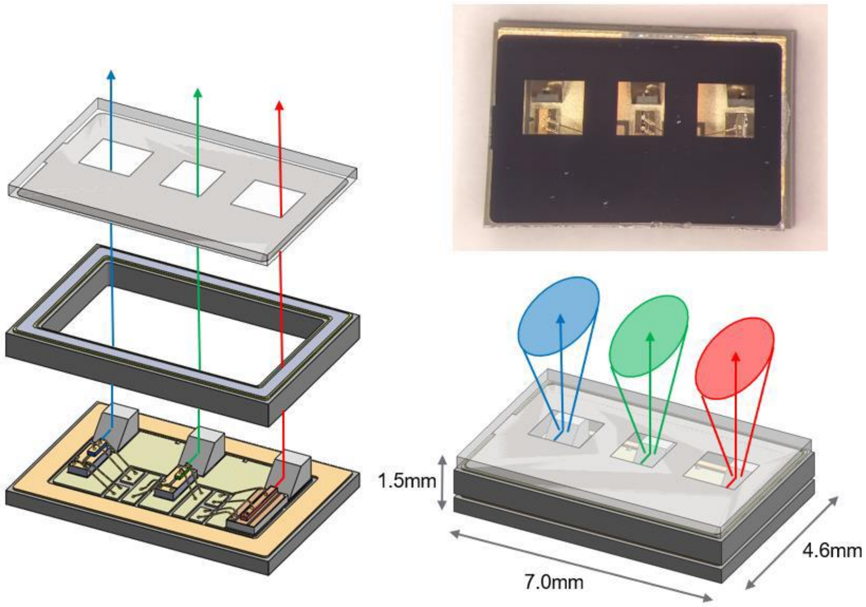

Fig 1. Ams-OSRAM showcased their state-of-the-art 'VEGALAS' RGB laser engine (without combiner) measuring only 4.6 mm x 7.0 mm x 1.5 mm (0.05 cc) [8].

In the remainder of this paper, we will first explain how ultra-compact RGB light engines can be created on a single photonic integrated circuit. Secondly, we will explain how the issue of speckle can be tackled by co-integrating a lithium niobate-based sub-system on the same chip.

2. Speckle-free Laser Engines on Chip

The integration of multiple lasers closely together is a critical aspect of advancing AR light engines. Placing different types of lasers closely together is made possible by innovative techniques such as micro-transfer printing (µTP). This advanced technique enables the precise placement and alignment of laser chiplets on a single platform. This integration is particularly advantageous for RGB lasers, as it allows for the combination of red, green, and blue laser chiplets in close proximity, just tens of microns apart. The level of control, compactness, flexibility, and especially scalability obtained with µTP is not achievable with other integration approaches such as wafer bonding or even flip chipping [6].

However, the real advantage is the possibility to create a low-loss external cavity laser (ECL). To this end, laser chiplets, also called coupons, will be transfer-printed in a recess on a SiN platform [9]. The SiN platform serves as an ideal choice for RGB lasers owing to its excellent optical and mechanical properties: low optical loss, wide transparency range and low thermo-optic coefficient.

Within this external cavity, a second material can then be transfer-printed: lithium niobate (LN) [10]. LN not only has a wide transparency range, which encompasses a significant portion of the visible spectrum, but also has a very high nonlinear $\chi^{(2)}$ coefficient, making it a highly regarded material for electro-optic phase modulation [11]. With this printed slab of thin-film lithium niobate, we will create a high-speed modulator. This modulator offers precise control over the laser wavelength and allows for the tuning of the external cavity to broaden the effective wavelength range.

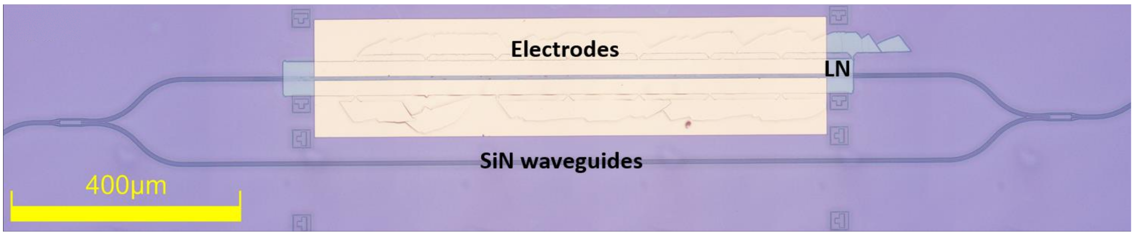

Fig 2. A high-speed modulator on SiN can be made using transfer-printed LN coupons [11].

Since the laser drivers generating the image modulate the laser coupons directly, a low-cost radio frequency (RF) oscillator and amplifier can be used to drive the LN modulator, e.g. by a sawtooth shape. Such high-frequency RF oscillators are cheap and readily available thanks to their usage in modern mobile networks. The fast-oscillating wavelength will then be perceived by the human eye as being effectively broadened, thereby reducing the speckle contrast.

3. Conclusion

Laser-based light engines for AR-displays are power-efficient, bright, and compact. Mitigating speckle in a compact and low-power manner remains, however, an open challenge. A light engine architecture is proposed that leverages recent advances in integrated visible photonics and heterogeneous integration techniques to create a densely integrated system. By micro-transfer printing RGB laser coupons and integrating a lithium niobate modulator, we aim for a speckle-free and compact light engine for future AR displays.

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