The Quantum Light Chip Technology

Ioannis Pitsios[1], Jonas Zeuner[1], Chiara Greganti[1]

ioannis.pitsios@vitrealab.com
[1]Vitrealab GmbH, Gutheil-Schoder-Gasse 17, 1230, Vienna, Austria (www.vitrealab.com)
Keywords: Laser Display, Display Backlight, Light source, Light engine, Integrated Optics.

ABSTRACT

The Quantum Light Chip is a light source that emits a dense array of laser beams from within a thin piece of glass, offering precisely controllable illumination properties, that can fundamentally change what is possible with current display technology, accelerating the development of the Augmented Reality (AR), Virtual Reality (VR) and 3D displays.

1 Introduction

Displays are among the most essential technology components of our age. We find them in all possible platforms, from commercial devices to medical, aerospace, and military systems. They are built in various sizes, shapes, and arrangements, to perform the most essential function for the human-machine interaction, that is the exchange of visual information.

The fundamental task of displays is to control light to produce images: the better a display can control light (i.e., direction, color, intensity), the higher the quality of the images is. Nowadays even the most advanced display technologies do not feature a high level of light control, because they typically employ incoherent Lambertian emitters, such as LED, OLED and uLED. This type of light source emits light in all directions (Fig. 1.a), over a large range of wavelengths, and is often limited in intensity, impacting the display performance in a variety of ways. For example, every light ray that doesn't reach the viewer's eye means brightness loss and wasted energy. Increasing the brightness of the source improves the display brightness but requires more power and often affects the color quality and the contrast ratio. Further, Lambertian sources perform very poorly for the next generation of displays, based on AR and holographic technologies. Lasers could overcome most of these issues, but the methods employed to date haven't allowed for their effective deployment.

2 Transforming Displays with Lasers

Lasers are among the most promising light sources for the next generation displays as they generate highly controllable light, with unparalleled brightness and very narrow wavelength spectrum. These features make them ideal light sources for displays and especially AR and holographic applications.

2.1 Current limitations of Laser Display Illumination

Although lasers offer great advantages for display illumination there are many technical challenges to overcome before utilizing them in displays. For example, lasers typically emit single laser beams with small cross sections, which are insufficient to illuminate entirely the surface of a display, especially in the case of large displays, like the smartphones and laptops displays. Expanding the beam with an optical element like a lens could solve this issue, but due to the Gaussian profile of the laser light one would have to expand it significantly and use only the central part of the expanded beam to uniformly illuminate a display surface, leading to reduced brightness and low energy efficiency; not to mention the sacrifice in compact form factor due to the use of a lens. Additionally, laser sources introduce an additional concern, that is the presence of coherent artifacts such as speckles and interference patterns.

Control of the spatial and temporal properties of the laser light is thus one of the most important challenges for the effective illumination of different display technologies.

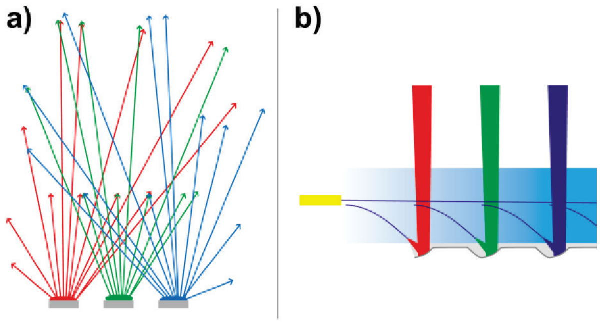

Fig. 1 Difference between (**a**) Lambertian emitters such as LEDs and (**b**) VitreaLab's Quantum Light Chip source. In (**a**) incoherent light rays are emitted in all directions while in (**b**) Laser light from a laser diode is propagating in the glass via integrated optical waveguides. The waveguides direct the laser light to nano-imprinted micro-mirrors that reflect it towards the output. At the output coherent Gaussian laser beams are emitted with specified direction, collimation and spacing.

2.2 The Quantum Light Chip Technology

The Quantum Light Chip is an integrated photonic platform that allows the spatial control of laser light on the micro scale.

Each chip contains hundreds to millions of precisely fabricated low-loss optical waveguides, embedded in common display glass via direct laser writing (Fig. 2.a). In this method a femto-second pulsed laser is focused within the glass and the glass sample is translated below the laser beam. Due to non-linear absorption the glass is locally heated and densified which in turn changes the refractive index (slightly increases it). This index change enables the guiding of light via total internal reflection, meaning that waveguide has been created. The waveguides used by VitreaLab are single-mode (TEM_{00}) and 2-3um in diameter, depending on the wavelength of the light guided and have very similar optical properties to a single mode optical fiber. Light is transferred from one waveguide to another via directional couplers (Fig. 2.b). A cascade of multiple such devices allows to distribute light from a single laser diode to millions of laser beams over the entire surface of the glass. The coupling parameters can be adjusted for each individual coupler, meaning that a very precise light intensity distribution can be achieved.

After the light has been distributed over the glass in the waveguide network, the laser light must be emitted out of the glass, typically normal to its surface. To this end, the waveguides are bend downwards and emit the light towards the glass surface where surface micro-optical components have been fabricated using nanoimprint lithography, a process well known for its cost efficient and high-quality optical manufacturing (Fig. 1.b).

The waveguides are terminated close to the glass surface and the guided light is emitted into a cone. This cone of light is then reflected by the micro-mirrors on the glass surface. The waveguide termination and the micro-mirrors position can be chosen and thus beams densities of up to 400ppi are possible. Furthermore, the micro-mirrors can be of arbitrary shape allowing to precisely control the laser beam collimation and direction at the output (Fig. 2.c).

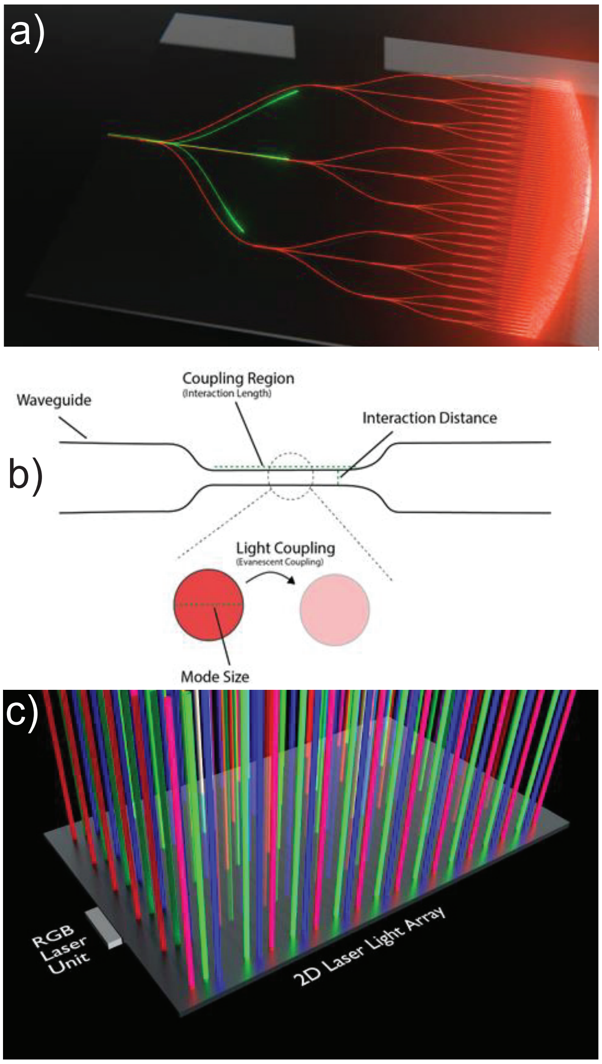

Fig. 2 **(a)** A waveguide network distributes light from one laser diode at the glass input over its entire surface. **(b)** In a directional coupler optical power is transfer between adjacent waveguides via evanescent field coupling. **(c)** A Quantum Light Chip emits dense arrays of Gaussian beams in all visible colors.

3 Applications in the various display technologies

In this section we outline how the Quantum Light Chip can be used as a light source for different display systems and its corresponding benefits.

3.1 LCD-based Displays

A Quantum Light Chip can be used as a backlight for LCD displays. For LCD modules with resolution up to 400ppi the Quantum Light Chip can provide pixel-wise illumination. Specifically, by tuning the spacing of the individual laser beams to match the liquid crystals grid, each beam can illuminate a single sub-pixel (Fig. 3). The beam passes entirely through the sub-pixel aperture without losses, leading to enormous brightness and corresponding energy efficiency gains. Furthermore, the LCD does not require any color filters and polarizers as the laser beams are colored and polarized. This not only contributes to the efficiency and brightness of the display, but additionally allows to achieve perfect color accuracy and very high contrast ratios.

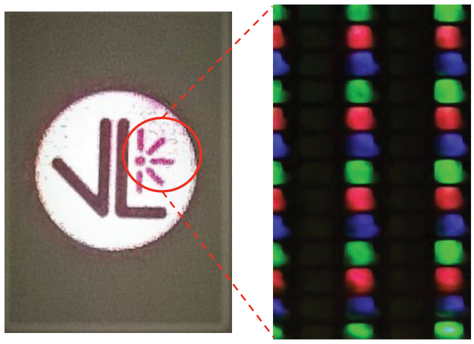

Fig. 3 A full color image displayed by a VitreaLab QLE prototype combined with a monochromatic liquid crystal display pixel grid. On the right, a zoom-in on the sub-pixel level shows the RGB laser beams illuminating each sub-pixel.

The Quantum Light Chip can also be used for illuminating ultra-high-resolution LCD displays (e.g., 2000ppi or more) in a flood illumination approach. In this case a diffuser must be introduced between the source and the liquid crystal layer to create a uniform light front. This approach is less efficient than the pixel-wise illumination as some loss is introduced but is still more efficient than other methods due to the light directionality.

3.2 Augmented Reality Displays

Augmented Reality (AR) goggles and Head Up Displays (HUD), are image-projection systems that overlay artificial images over the real-world vision and are among the major emerging display technologies. The biggest limitation for these systems is brightness, as they need to project crisp bright images on backgrounds illuminated by the sunlight. On a regular sunny day, the ambient background brightness is around 10.000 nits (white concrete wall), thus an AR display needs to be at least this bright to achieve a visible brightness contrast and requires at least 30.000 nits to be useable in all conditions. The brightest commercially available devices today do not exceed 2000nits.

Brightness is a term used extensively in the AR community to communicate the illumination properties of various AR products because this is the quantity perceived best by the end user. However, this term is not enough to describe the actual illumination efficiency of an AR system. For this, one should know additionally what the luminance of the AR light source is, and what is the electro-optical efficiency of this system. For example, the brightest AR goggles today achieve around 2000nits at the eyepiece (combiner/waveguide). This brightness is achieved by light sources that emit a minimum of around 3-5lm of light at their exit pupil and have an electro-optical efficiency in the range 7-10lm/W; hence, to achieve the target of 30.000nits the light source should be able to provide efficiently a few tens of lumens.

VitreaLab is developing an LCOS AR light engine based on the Quantum Light Chip capable to deliver 29lm in the exit pupil with a baseline electro-optical efficiency of 11.5lm/W. Furthermore, VitreaLab's AR light module is capable to perform dynamic beam steering, a process like local dimming, which can double the effective illumination efficiency, as the same amount of light can be used to illuminate a smaller area.

Laser illumination is probably the most effective and desired method to illuminate AR systems, however due to the coherent nature of laser light, laser powered AR systems suffer from coherent artefacts, especially speckle, which deteriorates the image quality. It is thus essential to eliminate these coherent effects. Our AR laser light engine can provide speckless images via a proprietary active de-speckling method.

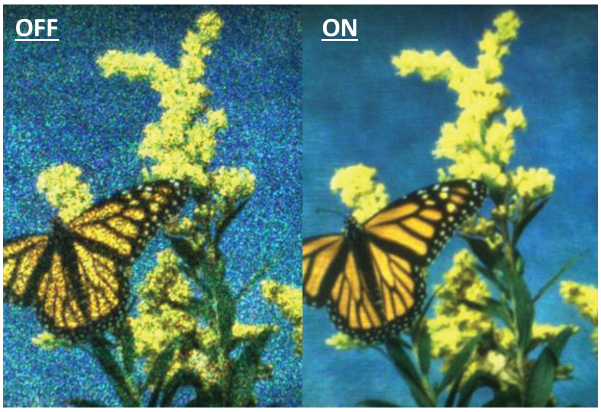

Fig. 4 A comparative demonstration of an image produced by VitreaLab's LCOS based AR engine, powered by a Quantum Light Chip laser illumination source, with active de-speckling deactivated (Left) and active (Right).

4 Conclusion

We presented a new type of display illumination technology called Quantum Light Chip that is based on glass embedded waveguides and nanoimprint technology. The highly controlled laser light allows for a great new versatility of display design in AR, VR, 2D and 3D displays.

Acknowledgment

The work presented has been co-financed by Austria Wirtschaftsservice (AWS), Austrian Research Promotion Agency (FFG), European Innovation Council (EIC) and European Research Council (ERC).