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ILLUMINATE

Singapore Photonics Workshop connects 135 members of academia and industry

The Singapore Photonics Workshop on 4 March was a successful exercise in bringing together members of academia and industry, with 135 attendees (81% of registrants). In total, 55 companies were represented at this major in-person LUX event, supported by NTU, NUS, SUTD, and A*STAR, which sought to:

- Identify strong collaborative academic/industry teams for industry-aligned funding opportunities guided by the National "Laser & Optics" for Precision Engineering: Technology Roadmap.
- Showcase the latest photonics technologies and innovation in the pre-defined areas and establish industry interest.
- Engage industry, define its needs, and identify proposal topics in translational research that help create a value chain in photonics.

Prof Tjin Swee Chuan

In his opening address, LUX Chairman Prof Tjin Swee Chuan discussed the industry landscape here for Precision Engineering (PE), Singapore's interest in photonics for PE: Lasers & Optics, as well as our national priorities for Lasers & Optics R&D in Singapore.

The workshop also saw keynote speech by Prof Nikolay Zheludev from NTU and the University of Southampton. Prof Nikolay is a pioneer and world leader in the fields of fundamental nanophotonics and metamaterials. His accolades include the President' Science and Technology Award in Singapore and he is a Fellow of the Royal Society (UK) and Member of the National Academy of Engineering (USA). His keynote on Picophotonics touched on the emerging science of interactions of picometer-scale objects and events with light.

Prof Nikolay Zheludev

Prof Simon See

The second keynote by Prof Simon See discussed the state of AI development, as well as the computational requirement for future models and the limitation of current computing technology. Prof Simon See is the Senior Director, Nvidia AI Technology Centre (GLOBAL) and Chief Solution Architect, Solution Architectural Group, NVIDIA CORPORATION. He is also a Professor and Chief Scientific Computing Officer at Shanghai Jiao Tong University, Professor in Beijing University of Posts & Telecommunications, Professor in in Universitas Indonesia (UI).

The Photonics Workshops sessions focused on three key topics: Session 1 - **Flat Optics** (moderated by Assoc Prof Luo Yu, NTU), Session 2 - **Imaging Systems, Metrology & Sensors** (moderated by Dr Cheng Fang, A*STAR, Advanced Remanufacturing and Technology Centre) and Session 3 - **Lasers and Fiber Optics** (moderated by Asst Prof Yoo Seongwoo, NTU) with breakout workgroups for each session. Flat optics is an emerging new technology that seeks to create more compact and efficient optical

Message from the Chairman/Co-director:

It has been a busy start to 2022 for us at the LUX Photonics Consortium.

In March, we were finally able to hold a major event in person: the Singapore Photonics Workshop, themed "Lighting the Way Towards the Next Wave of Photonics Innovation". It was great to be able to meet so many LUX members in person. The event received overwhelming response and unfortunately, due to restrictions on capacity, we had to turn away some of you who registered later. We seek your kind understanding on this matter.

In total, 135 attendees from IHLs, MNCs, SMEs and LLEs attended the workshop, which sought to bring the photonics community together to identify collaborative academic/industry teams for industry-aligned funding opportunities. The topics chosen for the workshop were guided by the National "Laser & Optics" for Precision Engineering Technology Roadmap. Through the talks, we highlighted a small portion of the latest photonics technologies and innovation in the pre-defined areas, with the aims of establishing industry interests and identifying research programmes that can be translated to products relevant to the industry.

The workshop had three breakout sessions – Flat Optics; Imaging Systems, Metrology & Sensors; and Lasers and Fiber Optics – with talks by speakers from A*STAR, DSO National Laboratories, NUS, NTU and SUTD. You can read more about the workshop and the various talks in the pages to follow.

Up next, on 5 April 2022, we will be bringing together research performers and companies for our second LUX-Enterprise Singapore Workshop Series: Co-packaged Photonics/ASICS & Heterogeneous Integration. The aim is to share the challenges, capabilities and new innovations; and to seek collaboration opportunities across MNC, local enterprises and the academia.

With the easing of COVID restrictions, most businesses and offices should be returning to "business as usual" mode of operation. At LUX, we will also be resuming our in-person quarterly networking sessions and re-establishing ties with our international partners. We will keep you posted on these activities and look forward to your participations and contributions to build a vibrant photonics community in Singapore.

Prof Tjin Swee Chuan
Chairman, LUX Photonics Consortium
Co-Director, The Photonics Institute

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE | The Photonics Institute | LUX PHOTONICS CONSORTIUM SINGAPORE components that can be integrated into different electronic devices. On "Optical Systems, Metrology & Sensors", discussion focused on high-throughput single-pixel optical spectrometer capable of operating at any wavelength range, and various types of optics-based biomedical sensors. During the session of "Laser and Fiber Optics", discussions focused on hollow core optical fiber for improved transmission of data for communication, scaling up of laser power, laser of wavelength ranges in UV and deep UV range as well as Mid-IR range, and how novel laser technology could find new application in IC fabrication, precision engineering, and remanufacturing in marine and aerospace.

In the following pages, you can read a summary of each talk by speakers from A*STAR, DSO National Laboratories, NUS, NTU and SUTD.

Session 1 – Flat Optics

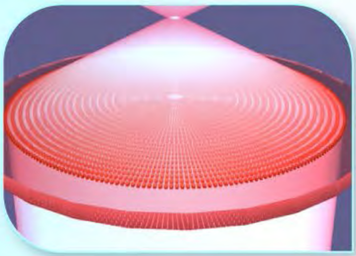
Flat optics and nanoantenna spatial light modulator technologies

Dr Arseniy Kuznetsov

Dr. Arseniy Kuznetsov, Institute of Materials Research and Engineering (IMRE), A*STAR

The rapidly developing photonics and optoelectronics industry seeks compact and efficient optical components that can be integrated inside mobile and wearable devices without introducing much weight and extra volume, while maintaining high efficiency and low cost. While conventional bulk optics experience fundamental limitations in miniaturization and efficiency at small dimensions, flat optics based on so-called metasurfaces could potentially solve these issues and revolutionize the optical industry. Metasurfaces are arrays of nanostructures, also called nanoantennas, which can efficiently interact with light at the nanoscale and change their phase and amplitude at dimensions that are smaller than the wavelength of light. This provides an opportunity to precisely control the wavefront of light with flat patterned surfaces, having sub-micron thickness, while also introducing additional functionalities.

At IMRE, we are developing three different types of flat optics technologies. First is related to conventional static optical components, such as various types of lenses, polarizers, beam splitters, holograms and others. We use metasurfaces to inscribe various phase profiles to transmitted or reflected light with high efficiency and sub-wavelength resolution. Apart from being compact and lightweight, many of these flat optical components can outperform their bulk optics analogues in terms of efficiency and complexity of optical functions (see Fig.1 Left). Second, we are developing tunable flat optics with individually-controllable nanoscale pixels. This technology provides a possibility to create tunable-focus lenses and spatial light modulators with sub-micron pixel size (much smaller than in currently available commercial products), which might become an enabling solution for future AR/VR and 3D dynamic holographic display technologies (see Fig.1 Right). Finally, we are also developing active metasurfaces interfaced with light-emitting materials for efficient fluorescence enhancement and full color conversion in sub-micron thick color converting layers, which can be used to create high-resolution RGB micro-LED displays. We are also working on ways to achieve nano- and micro-scale RGB lasers for making flexible micro-laser arrays for sensing and display applications.



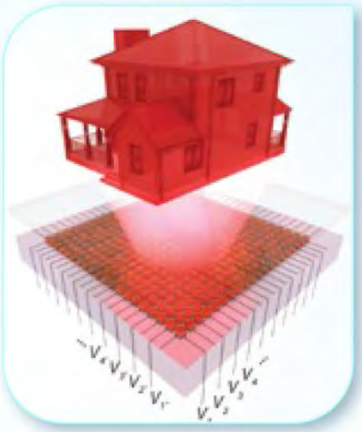


Fig.1 Left: *Artistic illustration of a high numerical aperture flat lens based on a metasurface.*

Fig.1 Right: *Artistic illustration of a spatial light modulator with a single electrically tunable nanoantenna as a nanoscale tunable pixel.*

Apart from the technologies mentioned, we are developing various up-scaling methodologies for flat optics component manufacturing, including 12-inch immersion photolithography and nanoimprint. We are also actively looking for industry partners to translate novel flat optics solutions to industrial products.

Microscale Prints with Structural Color for Anti-Counterfeiting

Assoc Prof Joel Yang

Assoc Prof Joel Yang, SUTD

The growing global challenge that is counterfeiting has caused financial losses in excess of half a trillion dollars annually and loss of lives, due to counterfeit drugs and critical system components. Unfortunately, optically-variable devices (OVD) that have historically provided protection can now be easily replicated.

Our group is working on developing new optical solutions that lead to next-generation anti-counterfeiting tags. These are machine-readable, easily recognizable, contain multiple covert information sets, as well as physically unclonable functions in a single print. Crucially, we utilize a broad range of the visible spectrum and produce structural colors that are vibrant out of a range of materials, e.g. metals, semiconductor, dielectrics and polymers.

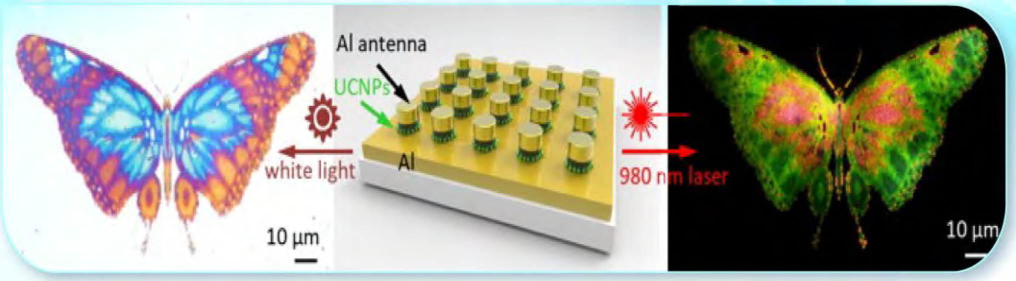


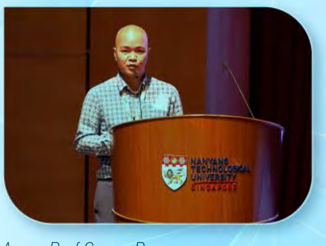
Figure 1. *Microprints exhibiting distinct color schemes under white light vs laser illumination by incorporating plasmonic resonators with upconversion nanoparticles. [Reproduced from Hailong Liu, et. al, Advanced Materials 2019]*

The platform technologies are in numerical simulations and designs of structural color, nanoscale printing using electron-beam lithography (EBL) and two-photon polymerization lithography (TPL), which enables 3D printing with 100 nm feature sizes. Examples of anti-counterfeiting tags include microprints incorporating upconverted fluorescent particles (Figure 1), and light-field prints consisting of 3D-printed microlenses with structural colors to produce up to 225 distinct images within a single print (Figure 2).

Figure 2. *"Fully-3D-Printed" Light Field Prints combining microlenses with structural color pixels to produce up to 225 image views at different viewing angles. [Reproduced from John Y.E. Chan et. al, Nature Communications (2021)]*

Session 2 – Imaging Systems, Metrology & Sensors

Optical Imaging, Filtering & Encrypting with Thin Scattering Media



Assoc Prof Cuong Dang

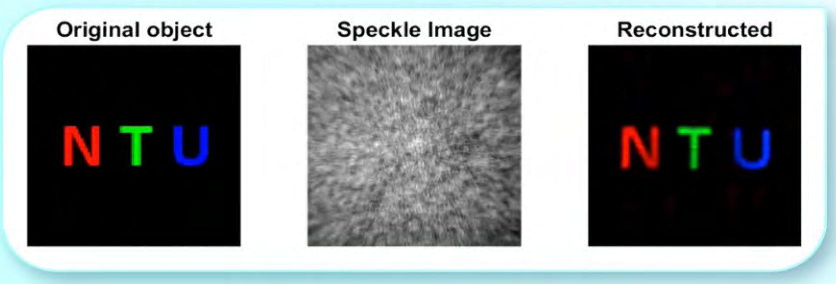
Assoc Prof (Steve) Cuong Dang, NTU

The technology is the result of a collaborative research project between NUS and NTU, and its essence lies with the understanding of light scattering through a thin translucent medium with the goal of imaging through biological tissues. The results go beyond biomedical-oriented research, showing many potential applications for optical imaging, filtering, and encrypting through a computational approach with natural or man-made scattering media.

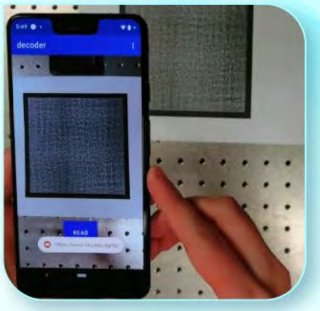
Multispectral imaging plays an essential role in many applications, from astronomical imaging and earth observation to biomedical imaging. Two typical approaches are currently used in multispectral cameras: (1) multiple optical filters in front of a camera to capture each spectral image at a time (multishot to achieve multispectral images); or (2) a dispersive medium (grating or prism) to trade-off spatial information to spectral information on a 2D imaging sensor (single shot).

Our technology does not require any filters or dispersive medium – not even a lens – for single-shot multispectral imaging. No expensive fabrication is required, the optics is simply a thin, flat rough piece of glass or plastic. End-users can enjoy an effortless optical setup, one as simple as a piece of frosted glass in front of a 2D imaging sensor (a scattering medium can be designed for additional purposes). A single shot provides a speckle image that encodes all the spatial and spectral information. Our demonstrations utilizing optical physics of strongly scattering media and computational imaging extract the spectro-spatial information of the object after post-processing.

The fundamental physics in our approach is the uncorrelation of speckle patterns at different wavelengths i.e. each wavelength of light passes through the scattering medium in a different way. The spectral information is naturally multiplexed in the total speckle pattern in photo taking and is computationally demultiplexed in post-processing. If the spatial information is not needed, the spectral information only can be extracted for spectrometer applications. Additionally, we can multiplex more information such as depth or viewing angles because of their uncorrelated speckle patterns. This will allow single-shot 3D imaging with a system as simple as a scattering medium in front of a 2D optical imager.



The understanding of spatial and spectral multiplexing helped us enhance the information security of an incoherent optical cryptosystem. This system only contains one diffuser acting as the random phase mask (RPM), incoherent light from a plaintext passes through RPM and generates the corresponding ciphertext on a camera. We can use this technology to make a more secure medium of information exchange through images, with its' advantage being the hardware-generated key. Our hardware's randomness (scattering media) is from nature (biological tissues or sandblasted ground glass), which is fundamentally different from the pseudo-random generation algorithm. For example, no one can duplicate a piece of chicken eggshell with the same roughness. In our demonstrations, different users with different hardware-generated keys open their own QR codes after scanning the same speckle pattern (e.g. right image).



The 2D imager limits the amount of information that can be captured. This is also the limit of our multiplexing capability. Certainly, higher-resolution, higher bit-depth imagers will enhance the multiplexing capability and the image quality. But our technology allows users/manufacturers to define the trade-off flexibly to enable many novel functions that complement the current camera. Our patent is ready, our proof-of-concept demonstrations have been done with a multispectral imaging system and mobile app.

High-Throughput Field-Deployable Spectroscopy for Next-Generation Sensors

Assoc Prof Zhou Guangya

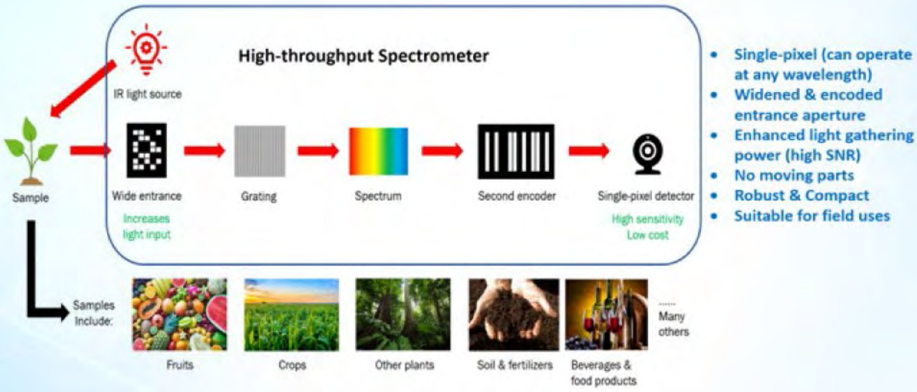
Assoc Prof Zhou Guangya, NUS

Conventional optical spectrometers have two major limitations. The first is the high-cost for non-visible wavelengths. It is well-known that silicon-based image sensors operating from wavelength 400 nm to 1100 nm are widely-available and generally of low cost. However, outside this spectral range where silicon is blind, the cost of image sensors increases drastically. Unfortunately for optical spectroscopy, many materials have characteristic absorption spectra at infrared (IR) wavelengths such as mid IR from 3 um to 5 um.

The second limitation is the small instrument throughput. Conventional spectrometers use a narrow entrance slit (typically with a micrometer-scale width), which severely limits the light gathering power (i.e. the throughput) of the spectrometer. Throughput is a critical performance indicator that determines the spectrometer's signal-to-noise ratio (SNR) and speed of spectrum measurement. Due to the nature of the conventional spectrometer design, enlarging the slit width increases the throughput but inevitably lowers the spectrometer's spectral resolution.

Here, we present a high-throughput single-pixel optical spectrometer as shown schematically in the figure. This type of spectrometer uses a single-pixel photodetector, enabling it to operate cost-effectively at any wavelength range, especially for applications where image sensors / detector arrays are expensive. The spectrometer also has a large encoded entrance aperture thus allowing a significantly enhanced light-gathering power, and hence it is capable of detecting very weak light signals.

In our demo system, we have used a large 3.2 mm X 3.2 mm entrance aperture and yet achieved a spectral resolution equivalent to a narrow entrance slit of 80 um width for a traditional spectrometer. In other words, we have increased the throughput of our spectrometer by more than an order of magnitude without sacrificing its spectral resolution. With our unique spectrometer design and advanced computational algorithms developed, the spectrometer is able to reconstruct accurately the spectra of weak light sources with high SNR. This is highly advantageous for IR and Raman spectroscopic sensing applications. Furthermore, this spectrometer is also robust with no mechanical moving parts, and can be made portable for field uses.



Overall, this type of new high-throughput single-pixel spectrometers show promise to be used in IR and Raman spectroscopic sensing in various application domains such as in food and beverage quality assessment, gas sensing, environmental monitoring, precision agriculture, industrial process control, internet of things, biomedical point of care testing, drug screening, and many others.

Imaging at Macro to Nanoscale – For Optical Metrology and Diagnostic Medical Applications

Assoc Prof Murukeshan Vadakke Matham

Assoc Prof Murukeshan Vadakke Matham, NTU

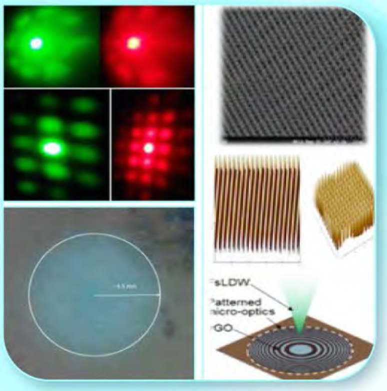
At COLE, we have focused our R&D on new technologies for imaging at macro to nanoscale, with specific applications in micro/nanoscale imaging, diagnostic biomedical optics, optical metrology, and optical fabrication & laser processing. These R&D projects integrate multi-disciplinary themes and aim to solve the challenges related to the current unmet needs of the industries. Here we highlight a few of our most recent works in this context.

Technologies developed in-house:

Micro- and nanoscale optics

Optics technology focusing on semiconductor, biomedical and energy sectors has recently seen the impact of nanoscale patterning, a challenging trend to achieve smaller features or devices with micro- or nano-scale features. This automatically demanded the need for achieving much smaller features beyond the forecasted sub- 30nm fabrication methodologies. Hence, there is a significant push for smaller dimensions recently that has posed many challenges. Technologies developed in-house in this context are:

(i) Multi-beam laser interferometric lithography system for conventional and near-field optics assisted patterning
(ii) Use of patterned structures obtained from (i) for semiconductor applications meeting the forecasted technology nodes of sub-30nm features by 2020
(iii) Novel configuration of layered plasmonic and gap-mode assisted structures for improved broadband absorption in thin film Si solar cells
(iv) Speckle lithography for novel nanoscale patterning. This has proven to make reliable hydrophobic, hydrophilic surfaces, and black or white silicon structures for potential industrial applications
(v) A multi-material 3D printing system: Micro and nano-scale high aspect ratio patterns for 3D printing with targeted applications in flexible electronics, sensors, and batteries

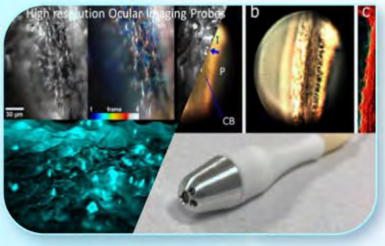


Patterning at micro to nanoscale

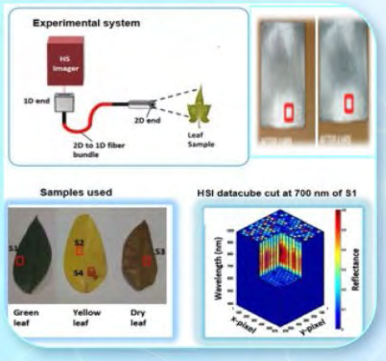
Biomedical optics – hybrid-modality high-resolution Imaging – for diagnostic biomedical imaging and sensing for disease diagnosis

Biomedical optics, an interdisciplinary branch of science and technology, uses optics for improving the basic understanding of biological processes, and enhancing the diagnostic efficiency and treatment of diseases. From this perspective, a recent challenge for medical diagnostics has been to come up with dual and multi-modality imaging for better diagnostic procedures. Major systems developed in this area include the following:

(i) GonioPEN for corneal imaging and glaucoma management
(ii) Bessel beam imaging system for high-resolution ocular imaging
(iii) Multi-modality flexible probe for in vivo optical biopsy
(iv) Tunable high-resolution optogenetics probe
(v) High-resolution specialty fiber probes for medical diagnostics
(vi) 4D hyperspectral probe
(vii) Imaging around opaque obstacles, which has found good applications in ocular imaging and follow-up procedures
(viii) Multi-modality imaging probes and equipment
(ix) High-resolution long working distance microscope
(x) New random light source for ultra-resolution bio imaging



High resolution Ocular Imaging Probes

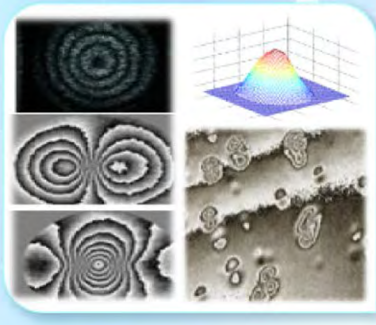


Hyperspectral imaging probe for engineering, vertical farming, diagnostic bio imaging applications

Optical metrology

Optical metrology has been widely employed as a key technique for modern industrial production, owing to its fast, precise and non-invasive measurement. We have developed new optical metrology concepts and equipment that can be used for a variety of surfaces ranging from rough to translucent to highly reflective. Applications range from aerospace to marine to healthcare industries. Equipment and concepts that are developed for current and future unmet needs of the industries are:

(i) Metrology concepts and systems for future aircraft or marine engines, and parts for roughness mapping, contouring and NDT
(ii) Very high-resolution imaging using specialised illumination beams for surface topography evaluations
(iii) Whole field non-destructive vision systems
(iv) Probes for inspection and measurement of inaccessible regions and channels



Optical Metrology and NDT

Session 3 – Lasers and Fiber Optics

Research on Sesquioxide-based Laser Ceramics and Lasers

Prof Tang Dingyuan

Prof Tang Dingyuan, NTU

Sesquioxide materials, such as Y_2O_3, Lu_2O_3, and Sc_2O_3, have cubic crystal structure, high thermal conductivity, small thermal expansion coefficient, and small phonon energy. They are considered as the most desired host materials for high-power solid-state lasers. In addition, they also have high chemical stability and plasma resistance, which can be useful in the modern semiconductor industry. However, as sesquioxide materials have extremely high melting temperature (>2400 °C), the growth of sesquioxide single crystals is very challenging, which has severely limited their applications.

In the past, we have been intensively working on the fabrication of various types of YAG, LuAG and sesquioxide-based laser ceramics. Using a special vacuum-sintering plus hot isostatic pressing fabrication procedure, we have successfully fabricated different rare-earth ions doped YAG-, LuAG, and sesquioxide-based laser ceramics with large size and high lasing effciency.

Taking the Y_2O_3-based laser ceramics as an example, our fabrication procedure starts with the synthesis of high-purity, well-dispersed nanocrystalline Y_2O_3 ceramic powders using a spraying chemical coprecipitation method; the synthesized nanocrystalline powder is cold isostatic pressed (CIPed) into green bodies, and then vacuum sintered and hot isostatic pressed (HIPed) under appropriate temperatures into the laser ceramics. As good dispersion nano-sized powders are used, the sintering temperature used is much lower than the melting temperature of the materials. Especially, different from the conventional fabrication of transparent ceramics, no sintering aids are used in our fabrication procedure. Therefore, our fabricated ceramic samples can have high material purity and lasing efficiency.

Using the fabrication technique, we have successfully fabricated a series of rare-earth ions doped sesquioxide-based laser ceramics, such as $Yb^{3+}:Y_2O_3$, $Yb^{3+}:Lu_2O_3$, $Nd^{3+}:Y_2O_3$, $Ho^{3+}:Y_2O_3$, and $Er^{3+}:Y_2O_3$, etc. Using a simple diode end-pumped two-mirror laser cavity configuration, we have demonstrated 38W CW $Yb:Y_2O_3$ ceramic laser emission at 1.06μm with an optical-to-optical conversion efficiency of 64%; in a Tm-fiber laser-pumped $Ho:Y_2O_3$ ceramic laser, we have generated > 200W CW laser emission at 2.1 μm, which is so far the highest ceramic laser output power reported at the wavelength; on a diode-pumped $Er:Y_2O_3$ ceramic laser, we also achieved >10W CW emission at 2.7 μm, which is the highest CW ceramic laser emission at the wavelength.

Samples of the fabricated laser ceramics

Finally, our fabrication technique can also be used to fabricate high-quality ceramic scintillators, opto-magnetic ceramics, etc. These ceramic materials also have a wide range of applications in modern science and technology.

Fibre-based ultrafast mid-infrared source at unprecedented power levels

Asst Prof Wonkeun Chang

Asst Prof Wonkeun Chang, NTU

Hollow core optical fibre traps and transmits light in its central hollow region, leading to three interesting implications: (i) Absorption in the waveguide material can be minimized as the light is tightly confined in the hollow region with only small overlap with the glass, offering fibre-optic guidance in non-conventional spectral regions, such as vacuum-ultraviolet and mid-infrared. (ii) Since the light is guided in the hollow region, the fibre's power-damage threshold is substantially enhanced, making it suitable for high-power applications. (iii) Strong light-matter interactions can be induced over a long and bendable length by filling the fibre with matter of our choice, and the light-guiding properties can be engineered by changing the fibre geometry or filling material.

These features make hollow core optical fibre an interesting platform for various applications. Further, the tremendous progress made in the last decade in hollow core optical fibre technology has seen its transmission loss come down dramatically, to compete now with standard single-mode optical fibre that forms the backbone of global communication networks. At NTU's Centre for Optical Fibre Technology (COFT), we have established the technical capability to tailor produce high-performance hollow core optical fibres for various applications as exemplified in Figure 1.

A focal point of our research is developing fibre-based novel light sources in vacuum-ultraviolet and mid-infrared, addressing the current lack of high-quality lasers in these spectral regions. As illustrated in Figure 2 (below), the concept utilizes a gas-filled hollow core optical fibre to stage phase-matched frequency conversion of near-infrared pump to other spectral regions.

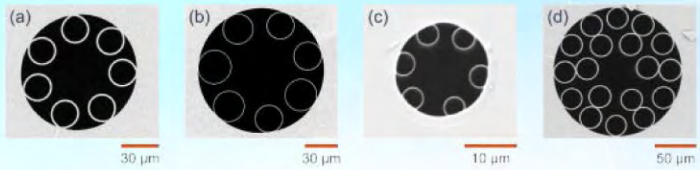


Figure 1. Cross-sectional images of hollow core optical fibres fabricated at COFT. (a) Hollow core optical fibre that guides in the 1.7–2.2 μm region. (b) Large-mode-area hollow core optical fibre for mid-infrared guidance. (c) Small-mode-area hollow core optical fibre produced via tapering for mediating low-energy-threshold light-matter interactions. (d) Double-ring hollow core optical fibre for low-loss guidance in near-infrared.

The idea has been extensively tested for developing wavelength-tuneable ultraviolet sources and is now a well-established technique. Recently, we also devised a new approach to reduce the pump pulse energy requirement of the process to a level that can be delivered by a compact laser oscillator [1]. This finding paves an avenue to miniaturise the ultraviolet light source.

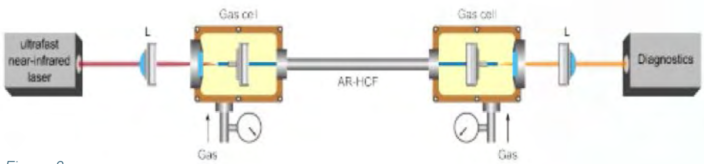


Figure 2.

While swift progress has been made in ultraviolet generation using the platform, not many research activities have been reported in the mid-infrared region. Lately, we made a breakthrough, demonstrating high-power femtosecond pulse generation in the 3–4 μm spectral range in a gas-filled hollow core optical fibre [2]. A μJ-level single pulse energy is achieved in the mid-infrared amounting to tens of megawatts, which is three orders of magnitude higher peak power than any other fibre-based mid-infrared sources reported to-date. This, combined with the high power-handling capability of hollow core optical fibre, presents a potential pathway to build a mid-infrared supercontinuum source with a small footprint and exceptional stability. It promises to be a powerful new tool for ultra-high sensitivity molecular spectroscopy.

[1] Xiong D, Luo J, Hassan MRA, Wu X, Chang W, Low-energy-threshold deep-ultraviolet generation in a small-mode-area hollow-core fibre, Photonics Res. 9, 590–595 (2021).

[2] Deng A, Gavara T, Hassan MRA, Hasan, MI, Chang W, Microjoule-level mid-infrared femtosecond pulse generation in hollow-core fibres, under-review.

Robust Phase Modulation Technique for Suppression of Stimulated Brillouin Scattering in Narrow Linewidth Fiber Amplifiers

Ms Wendy Lim

Ms Wendy Lim Wei Ying, DSO National Laboratories

Beam combining of fiber lasers has been widely studied by many research groups in recent years. By taking advantage of the high intrinsic brightness of fiber lasers and overcoming several fundamental limitations of single-fiber lasers, it offers one of the most promising approaches to scale the power of laser systems. Brightness scaling through beam combining of fiber lasers, however, necessitates the development of narrow linewidth fiber lasers with high beam quality.

One key challenge lies in overcoming stimulated Brillouin scattering (SBS) at high powers in such fiber lasers, and a commonly used method is to broaden the laser linewidth through phase modulation.

In this talk, we presented on the filtered pseudorandom binary sequence (PRBS) phase modulation scheme, which has previously been shown to simultaneously enhance SBS suppression and spectral brightness relative to a fiber laser under an unfiltered modulation scheme. We demonstrated how filtering distorts the optical spectrum of the phase-modulated laser and derived an optimization strategy for such filtered PRBS phase modulation schemes.

Through numerical simulations of the filtering effects on the optical spectrum, we determined the optimal ratios of the filter bandwidth to the PRBS modulation frequency to be 0.63, 0.56, 0.50, and 0.44 for bit numbers k = 7, 8, 9, 10, respectively. Applying this optimization strategy with a filtered 4.6 GHz PRBS scheme, we demonstrated a 1 kW all-fiberized narrow linewidth amplifier, with a near-diffraction limited beam quality of M2 ~ 1.27.

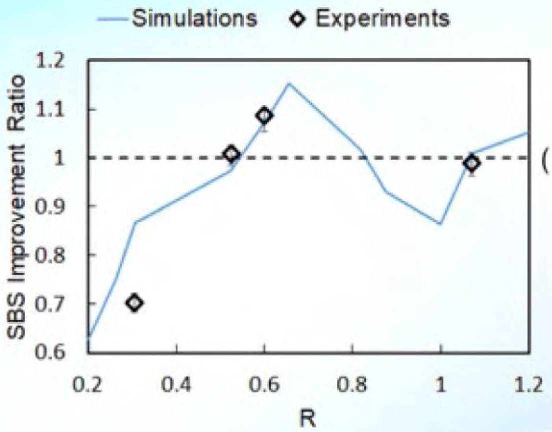


Figure 1: *SBS improvement ratio's dependence on the low-pass filter to modulation frequency ratio R, for k=7. Optimization strategy is to select an operating R where SBS improvement ratio outperforms unfiltered case. For R > 1, the threshold improves due to the drop in spike height, but the filtering becomes less effective in removing the self-seeding sidelobe and reducing the laser linewidth.*

New Industry Members Introduction

AGC

The AGC group's business extends into four fields: glass, electronics, chemicals, and ceramics. Through world-leading technologies and expertise developed over more than 110 years of technological innovation, we offer a diverse lineup of products for customers across a wide range of industries. From architectural glass and automotive glass and extending to display glass and electronic materials—as well as high-function materials such as chemicals and ceramics—the AGC group proposes new solutions from its unique perspective as a material manufacturer. To further enrich society, the AGC group pushes the limits in the creation of new standards of value.

Product lineup for Optical Materials include:

- DOE / Diffuser
- Glass Ceramics Substrate for LED and semiconductor laser
- Optical Planar Devices for optical imaging device
  - Micro lens array
  - Transmission grating
  - Wave plate element
- IR cut filter for cameras
- Aspherical Glass Molded Lenses for camera, projectors, sensors, IR analysers
- Micro Lens Array for cameras, projectors, light control equipment
- Optical Thin Films
  - Antireflection Film
  - Beam Splitter
  - Interference Filter (Dichroic Mirror)

SIMTRUM Pte. Ltd is a pioneer in photonics eCommerce platform in Singapore. The idea was conceived based on the co-founders' ambition to make photonics products more accessible and affordable to customers. The products are categorized on the website by application, namely:

- Light generation products such as lasers and light sources.
- Light analysis such as spectrometers, photo detectors, power meters and beam profilers.
- Imaging solutions including hyperspectral and multispectral cameras.
- Optoelectronics products such as pulse generators as well as high-speed, high-resolution time controllers.

SIMTRUM's technological capabilities include designing and manufacturing fiber and Raman spectrometers, diode pumped solid state (DPSS) lasers, UV direct laser writer and microscopy solutions. With sales network in both Singapore and China, SIMTRUM is well positioned to address new and challenging applications. The team members consist of a diverse mix experienced industry professionals as well as Ph.D holders. In addition to products and solutions, SIMTRUM also provide project consultation service for custom solutions. For more information, please visit www.simtrum.com

Synopsys Optical Solutions Group is a leading developer of optical design and analysis tools that model all aspects of light propagation, enabling users to produce accurate virtual prototypes leading to manufacturable optical systems.

CODE V Optical Design Software

CODE V is used for the optimization, analysis, and tolerancing of image-forming optical systems and free-space photonic devices. Its capabilities include local and global optimization for optics, MTF-based tolerancing, partial coherence analysis, polarization ray tracing, lens cost appraisal, etc.

LightTools Illumination Design Software

LightTools is a complete optical design and analysis software product featuring virtual prototyping, simulation, optimization, and photorealistic renderings of precision illumination applications. From LCD displays to projector systems, LightTools supports all aspects of illumination design projects.

LucidShape Automotive Lighting Design Software

The LucidShape product family provides a complete set of design and analysis tools for automotive lighting. With dedicated algorithms optimized for automotive applications, LucidShape facilitates the design of automotive forward, rear and signal lighting, and reflectors.

RSoft Photonic Device Tools

The RSoft Photonic Device Tools provide the industry's broadest selection of simulators and optimizers for passive and active photonic and optoelectronic devices. RSoft enables rigorous modeling of nano textured optical structures and diffraction analysis as well as simulations of complex optoelectronic devices.

Syswell Technology is a spin-off from NTU formed in 2020. We have developed a proprietary wireless FBG (Fiber Bragg Grating) strain sensor system for the construction and geotechnical service industries. Our sensors offer the following features:

High-quality data:

Our sensors are robust and highly sensitive. They are less prone to interferences compared to traditional electrical sensors. They can be easily redeveloped into measure other parameters.

Miniaturized sensors:

The detection in our specialised sensors is intensity based. This eliminates the need of interrogators. We also do away with lengthy optical fibres. These innovations bring down the price and the size of the sensors. This allows easy deployment of the sensors at low costs.

Remote monitoring:

ndividual sensors are equipped with wireless transmitters. This enables remote monitoring. Data are sent real time to a centralised location. When anomalies are detected, alerts and warnings can sent quickly.

Data analysis:

Sampling points and frequencies can be significantly increased with minimal manpower. This allows easier interpretation and better predictive analysis to prevent safety issues in buildings and other civil infrastructure.

LUX-Enterprise Singapore Workshop Series: Co-packaged Photonics/ASICS & Heterogeneous Integration

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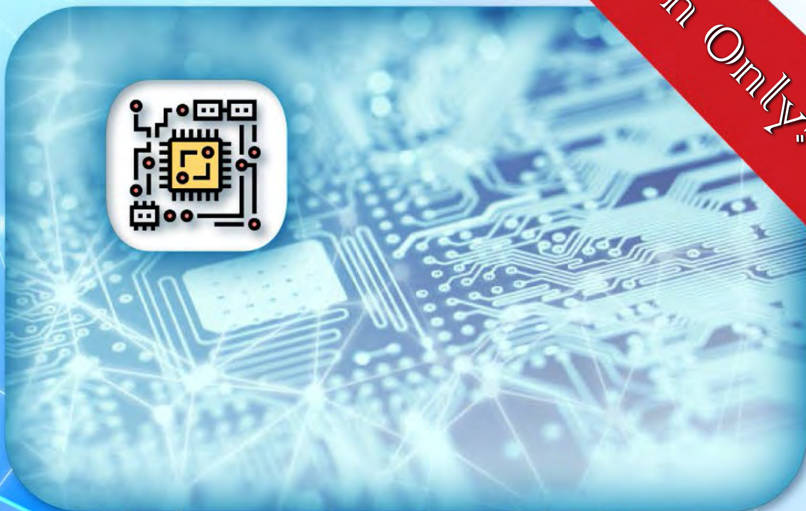

Date: 5th April 2022, Tuesday
Venue: NTU Innovation Centre Theatre (71 Nanyang Drive, Level 3, Singapore 638075)
Time: 9.00am to 1.00pm
Mode of participation: In-person

2022 2nd Qtr Members' Meeting

Date: 8th June 2022. Wednesday • Venue: NTU (TBC)
Mode of participation: In-person

Singapore Photonics Workshop
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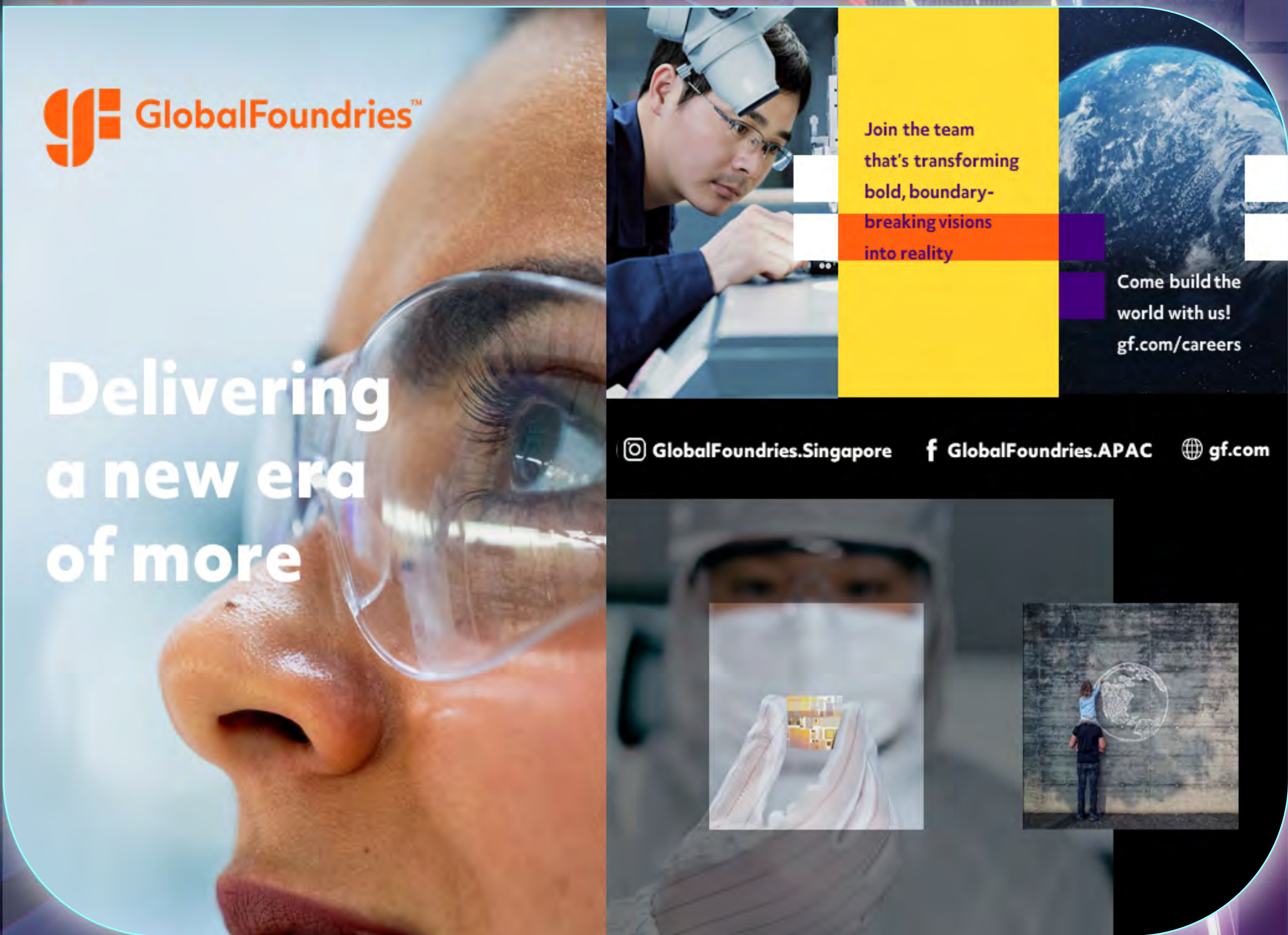

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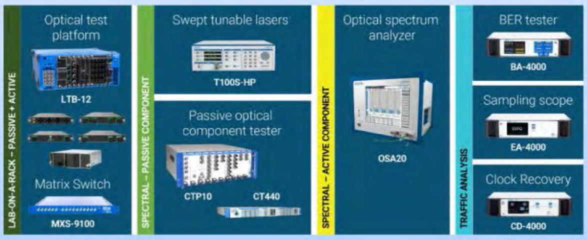
EXFO develops smarter test, monitoring and analytics solutions for the global communications industry. We recognize that component manufacturers need a turn-key solution that enables end-to-end testing in volume production settings. EXFO leads the industry in the relatively new domain of Photonic Integrated Circuit (PIC) testing, with hardware and software solutions that are automated, scalable, fast, accurate, and cost-optimized. EXFO's solutions can interoperate with any third-party instrumentation such as wafer disc handling systems.

EXFO has the fastest PIC testing system on the market, with repeatable measurements using "one dynamic range" type optical detectors.

The solution integrates various components on a single chip, increasing functionality along with increased density, reducing cost of production and lowering energy requirements. Innovation in light coupling methods has made wafer-level testing possible for mass production, simplifying testing, reducing test time per unit, and avoiding bottlenecks.

With proven unique and patented advantages, EXFO's high-end passive and active optical component test solutions portfolio sets the bar for testing, regardless of form factor, including wafer disc level, bar, die, or packaged components. And EXFO's PIC test solutions are automated, with optical synchronization that provides the most accurate measurements.

Innovative PIC testing solutions



MPI-EXFO automated wafer-level testing of photonic integrated circuits. EXFO's solutions can interoperate with any third-party instrumentation such as wafer disc handling systems.

In.D Solution Pte Ltd is a trusted and reliable provider of automated and cost-effective vision inspection solutions based in Singapore.

In.D Solution has created a niche for itself by providing innovative and tailored inspection solutions i.e optics, software, and reject modules for businesses across Southeast Asia, Europe, South America, and East Asia.

With years of close liaison with the key semiconductor players, we are now one of the leading AOI solutions provider, operating from multiple facilities across Asia.

Our key products include automated vision inspection machines for Wafer, Lead Frame, Die & Wire Bond, and X-ray Image Analyser.

For more information, please visit our website at www.in-ds.com

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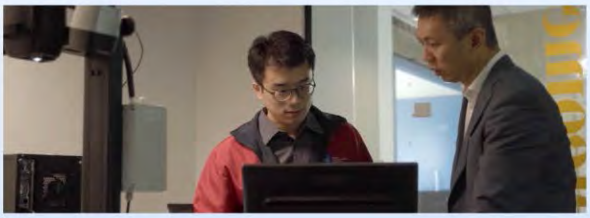
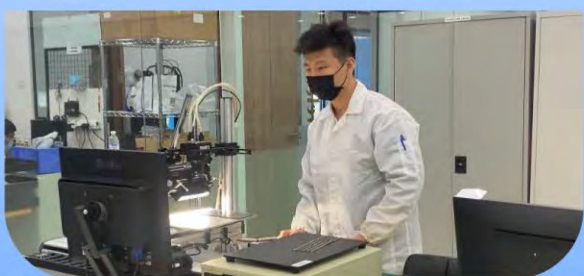
JM VisTec was established in 2004 as a machine vision specialist in Singapore. We represent global renowned brands of industrial components for machine vision. We are fully equipped for all kinds of vision applications and had crossed several milestones over the year. With manufacturing industry advancing into i4.0, we see ourselves value-adding to the industry and you as a solution provider, especially in 2D & 3D inspections, and Artificial Intelligence.



As a machine vision solution provider, we are keen on exploring and deploying cutting-edge technology solutions aimed at providing flexible manufacturing processes, improving productivity, and lowering cost. With our development of 3D Fringe Projection Laser Scanner – a customisable optical non-contact measurement instrument which aim to benefit high mix, low volume production. With high speed and precision, it can be used in 3D positioning and automatic grasping.

Next, 3D Confocal Microscope is our patented technology using only one image to measure the 3D topography of the entire surface, which is suitable for high-speed 3D topography measurement and defect inspection. Products and solutions that we provided are readily embedded in implemented Industry 4.0 solutions associated with connectivity, real-time production-performance monitoring, data analytics, simulation, and additive manufacturing.



OptoSigma®
SIGMAKOKI Group

OptoSigma Southeast Asia belongs to the SIGMAKOKI Group, a Japanese company that manufactures and supplies optical components and solutions, since 1977. With over 40 years of experience, OptoSigma has the expertise and know-how in this field that allows it to be a proud global supplier of high quality and high precision light and laser solutions. OptoSigma has a strong capability in system integrations, and welcomes product customizations even for small orders.

With a strong dedication in serving the optics and photonics community, OptoSigma has partnered with a start-up company to manufacture a Microsphere Optical Microscope with breakthrough technology. Likewise, we look forward to new opportunities of project collaborations with industrial and academic bodies.

Our standard catalogue offers over 20,000 optical & precision products, which are available on our E-Commerce store, with the following product lines: Optics, Opto-Mechanics, Manual Stages, Motorized Stages, Optical Tables, Fiber Optics, Laser Safety and Light Sources & Laser Analysis.

Established in 2019, the headquarters of its Southeast Asian office is located in Singapore, with its primary business function in the sales of optical equipment and system integrators within the Southeast Asian region.

Find out more about us here.

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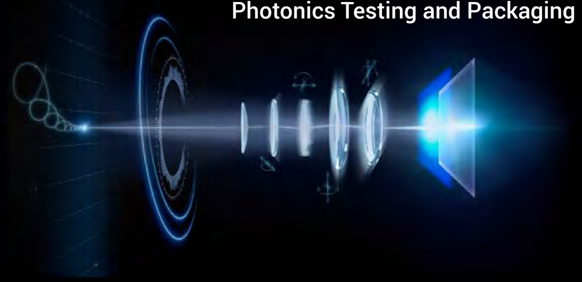

Fast and Precise Active Alignment for Testing, Assembly, and Packaging in Numerous Photonics Applications

Thanks to the immense transmission capacity and low energy consumption, optical communication is penetrating ever deeper layers of communication networks. Servers are increasingly being connected via glass fibers and also within computers more and more functionalities are being transferred to the medium of light. Placing optical components on silicon semiconductors and creating optical connections are recurring process steps in the production and quality assurance of silicon photonic components (SiPh) and photonic integrated circuits (PICs). Often, transverse tolerances of well below 50 nm are required. Therefore, precision, velocity, and a high degree of automation of the alignment are indispensable for the functionality and cost of manufacturing SiPh and PICs.

PI's tried and tested Fast Multichannel Photonics Alignment-Systems (FMPA) are faster than conventional methods by up to two orders of magnitude and they help to make this critical process economically viable. Starting from quality assurance for optical devices/elements at wafer level up to the final assembly, PI offers complete solutions for different chip designs, formats, and tasks. Only recently, the FMPA technology has also successfully been used to locate and characterize atomic-scale single-photon emitters that show valuable quality for quantum work.

Find out more at:

https://www.pi-southeast.asia/en/expertise/markets/photonics/

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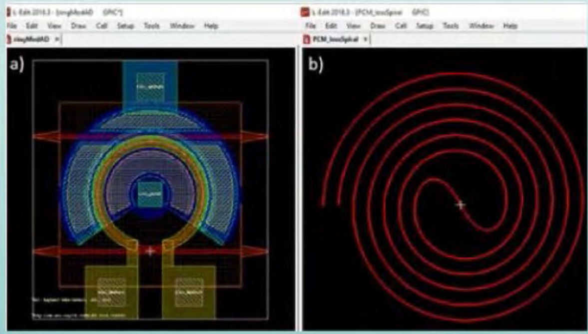

Layout driven design with L-Edit Photonics

https://resources.sw.siemens.com/en-US/white-paper-layout-driven-design-with-l-edit-photonics

Abstract:

Advances in integrated circuit technology and fabrication have made it possible to leverage traditional CMOS fabrication processes and materials and apply them to the design of Photonic Integrated Circuits (PICs). The combination of PICs with traditional electronic integrated circuits, called integrated photonics, is the ability to move, modulate, and detect light on a single IC. While there is a very established CMOS IC design flow with mature EDA tools, we are only now seeing the same efficiencies, reliability, and scale emerge for photonics design. Even for relatively simple designs, photonics presents physical and analytical challenges that require unique, dedicated methods that traditional electronic IC design does not employ.

In this whitepaper, learn how SiDx Inc., a medical device company, used L-Edit Photonics to address PIC challenges, and complete their integrated photonic IC.

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