Inverse-designed meta-optics for light sorting

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Colour cameras utilize absorptive filter arrays atop the image sensor to spectrally discriminate light into red, green and blue (*RGB*) bands. These colour filter arrays (CFAs) are typically arranged in 2x2 unit cells (*RGGB* Bayer kernel) and tessellated across the image sensor (**Fig.1A**). Albeit providing spectral sensitivity, this spatial arrangement means only 50% of the total incident light reaches the green pixels, 25% the blue pixels and 25% the green pixels. Further, as the absorptive dyes themselves only transmit ~40% light, it means in combination ~70% of incident light upon the sensor is lost. As the number of spectral bands increase (i.e. with multispectral sensors) or as the image sensor pixel sizes shrink, this light loss problem worsens. With smartphone pixels sizes currently ~1um^2 and growing demands for low light, low power consumption optical imaging, improvements in CFA technology is critical [1,2].

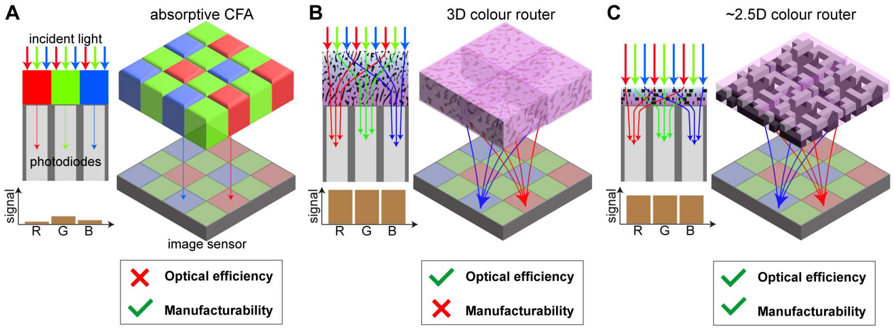

Fig 1. A. *Conventional RGB Bayer absorptive colour filter array (CFA), where separate absorptive filters spectrally discriminate the incident light.* ***B.*** *An alternate approach whereby sub-wavelength scatterers (3D distribution) route the light to specific pixels, thereby increasing the output signal.* ***C.*** ~2.5D meta-optic colour router.

In recent years, nanophotonic colour routers (*light sorters*) have been proposed as an alternative filtering approach to absorptive CFAs [1,3]. Rather than absorb, colour routers split the incident light into separate colours (wavelengths) and *route* the energy to specific pixels (**Fig.1B**). Colour routers are composed of low loss dielectrics and whose structure is typically determined using computational inverse-design algorithms [4]. The meta-structure is composed of many sub-wavelength scatterers, with a designed volumetric distribution such that light is routed to different output positions. Optical efficiencies as high as ~95% have been reported [3], however these studies are predominantly theoretical due to nanofabrication difficulty of such 3D distributions.

In this project, we will develop generalized light sorters based on inverse-designed meta-optics to efficiently route different wavelengths to different spatial positions. Our approach will employ 2D and ~2.5D meta-optic approaches (**Fig.1C**) in order to increase manufacturability while maintaining high optical performance (transmission efficiency, spectral sensitivity, angular sensitivity). As the designs quickly surpass the capability of human intuition, the project will look to apply machine learning based inverse design towards the design of meta-optic light sorters [4]. The research will prioritize design-for-manufacture and experimental validation will be realized through multi-layered nanofabrication technology. Our original focus will be towards efficient RGB light sorting, however due to the generalization of our approach, this work may be extended to additional applications. For example, to longer waveband spectral imaging in the short- to-mid wave infrared routing—due to the difficulty in achieving absorptive dyes at these wavelengths—and polarimetric imaging, which experiences comparable efficiency problems but now with routing linear polarization states instead of micro-pixelated wire grid polarizers. Further, we envisage this project may expand to other imaging and sensing architectures which could benefit from light sorting, including plenoptic imaging and chiral sensing.

The Department of Physics at Exeter has extensive expertise across optical physics, photonic device development and metamaterials. The student will have access to world-class research facilities—including state-of-the-art nanofabrication cleanrooms, high performance electromagnetic simulation software, and laboratories for electro-optical characterization. Dr. C. Williams (PI) develops novel imaging and sensing technologies based on engineering nanoscale light-matter interactions (examples highlighted in **Fig 2**).

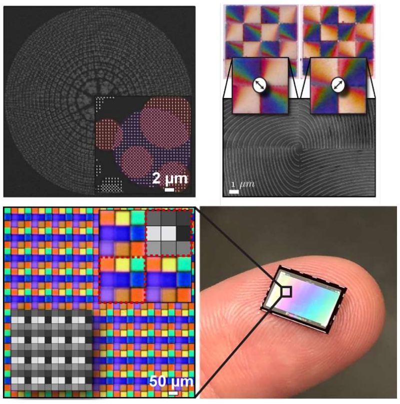

Fig 2. *Examples of nanophotonic devices developed by Dr. C. Williams*

References

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[3] Zhao, N., Catrysse, P.B. and Fan, S., Adv. Phot. Res., 2: 2000048 (2021)

[4] Li, Z., et al., ACS Photonics 9 (7), 2178-2192 (2022)