Shift-Free Wide-Angle Optical Thin-Film Metamaterial Notch Filter for Visible Laser Protection Systems

PRIFYSGOL BANGOR UNIVERSITY

J.N. Monks[1], L. Yue[1], B. Yan[1], A. Hurst[2] & Z. Wang[1]
1. School of Electronic Engineering, Bangor University, United Kingdom. LL57 1UT.
2. Qioptiq Ltd, St. Asaph, Denbighshire, United Kingdom. LL17 0LL.

Introduction

Laser striking is a growing safety concern for pilots and aircraft passengers and there is a great need to develop a wide-angle and shift-free laser filter and protection device. This poster presents one of such design that can effectively block out a Class 3B 532 nm green laser with an Optical Density (OD) of 1.88+ for all polarisation states over a wide range of incident angles up to 85 degree. The design consists of anti-reflection layer, active blocking and substrate layers. The central active blocking layer is designed to be a metamaterial composite media made of silver nanoparticles (AgNP) organised in a three-dimensional (3D) primitive hexagonal Bravais lattice configuration and embedded in a high-index dielectric of Zinc Sulphide (ZnS). The designed filter can be placed onto a number of devices ranging from personnel goggles to aircraft windows. The work may lead to the realisation of next generation laser protection devices that are currently sought by major aerospace companies and government defence agencies.

Statistics

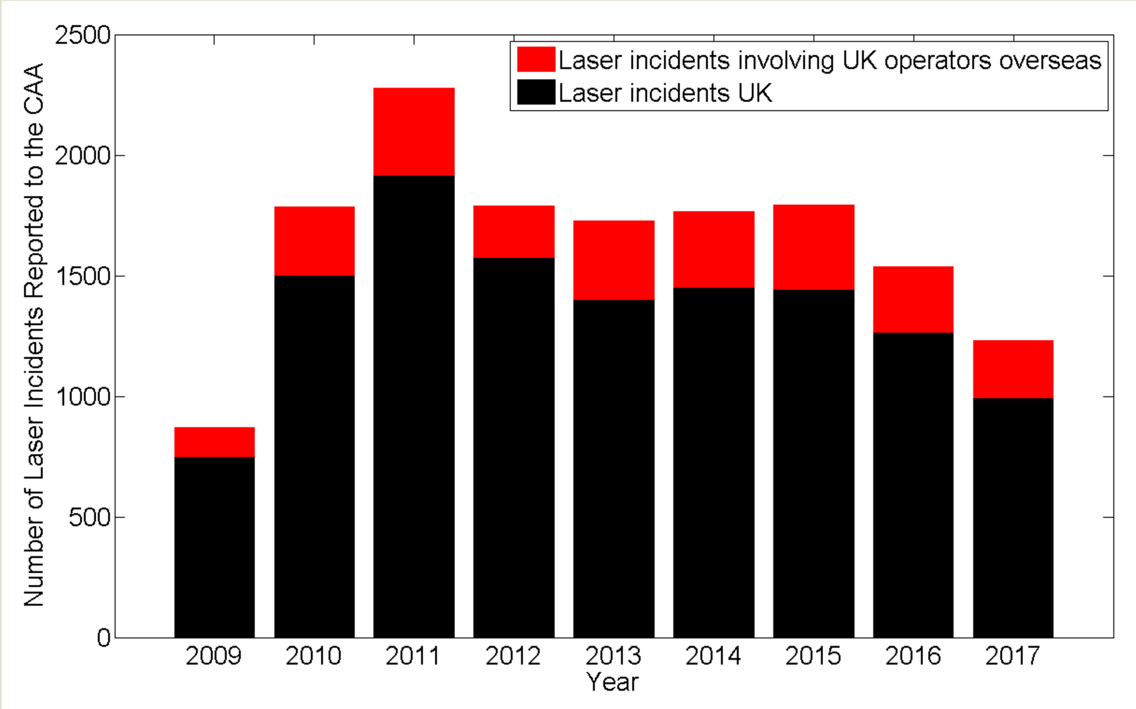

Fig. 1. Laser incidents reported to the UK CAA [1].

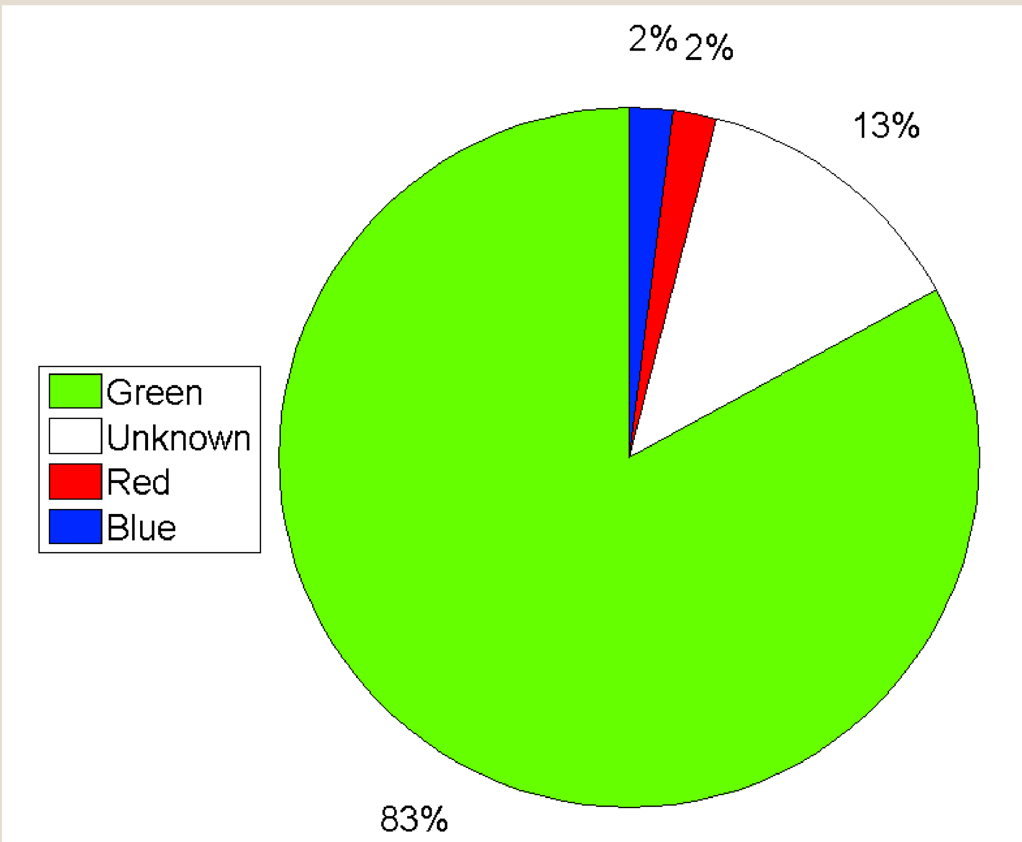

Fig. 2. Laser illumination events by laser colour reported to the UK CAA in 2016 [2].

Example of Existing Technology Limitations

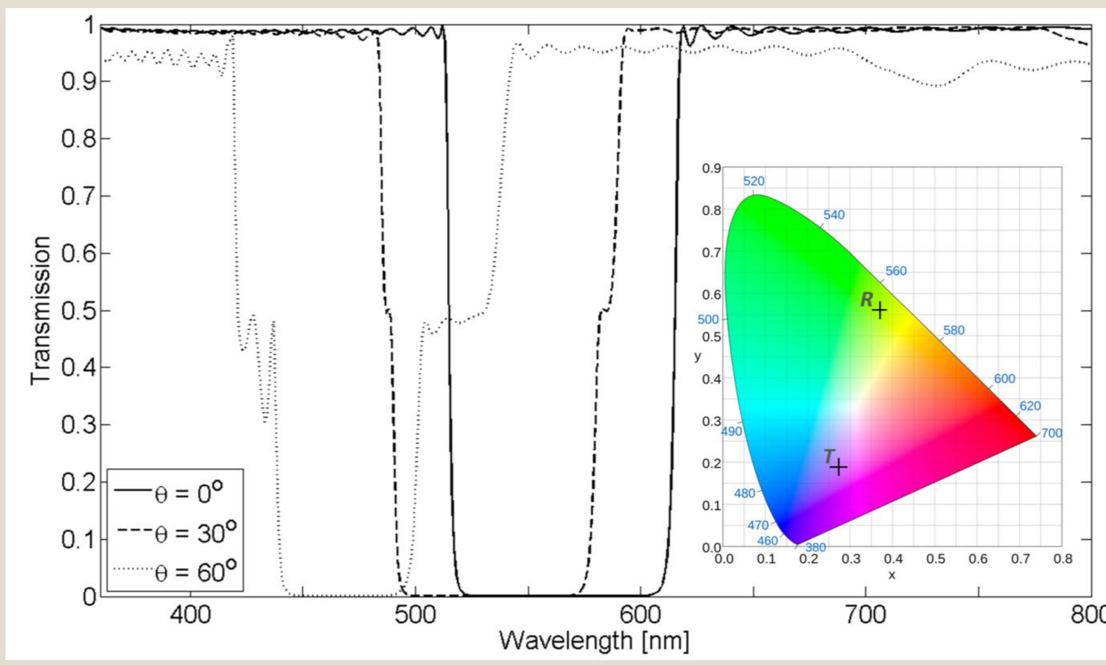

Fig. 3. Transmission of a traditional optical thin film filter versus wavelength for incident angle at $\theta = 0^\circ$, $\theta = 30^\circ$ and $\theta = 60^\circ$. The solid, dashed and dotted lines denote the cases of the incident angle. Insert shows the CIE 1931 colour map for the transmission (T) and reflection (R).

Conceptual Aim

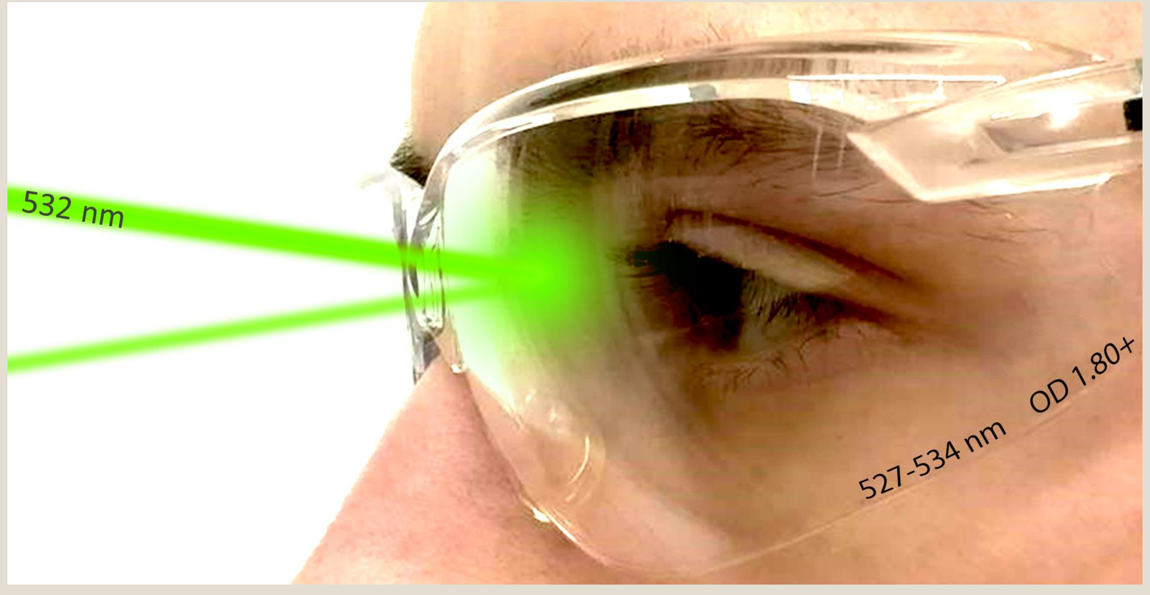

Fig. 4. An Artist impression of the conceptual aims for an optical metamaterial notch filter on personnel goggles, deflecting a 532 nm laser beam, with a bandwidth smaller than 50 nm.

Proposed Nano Configuration Design

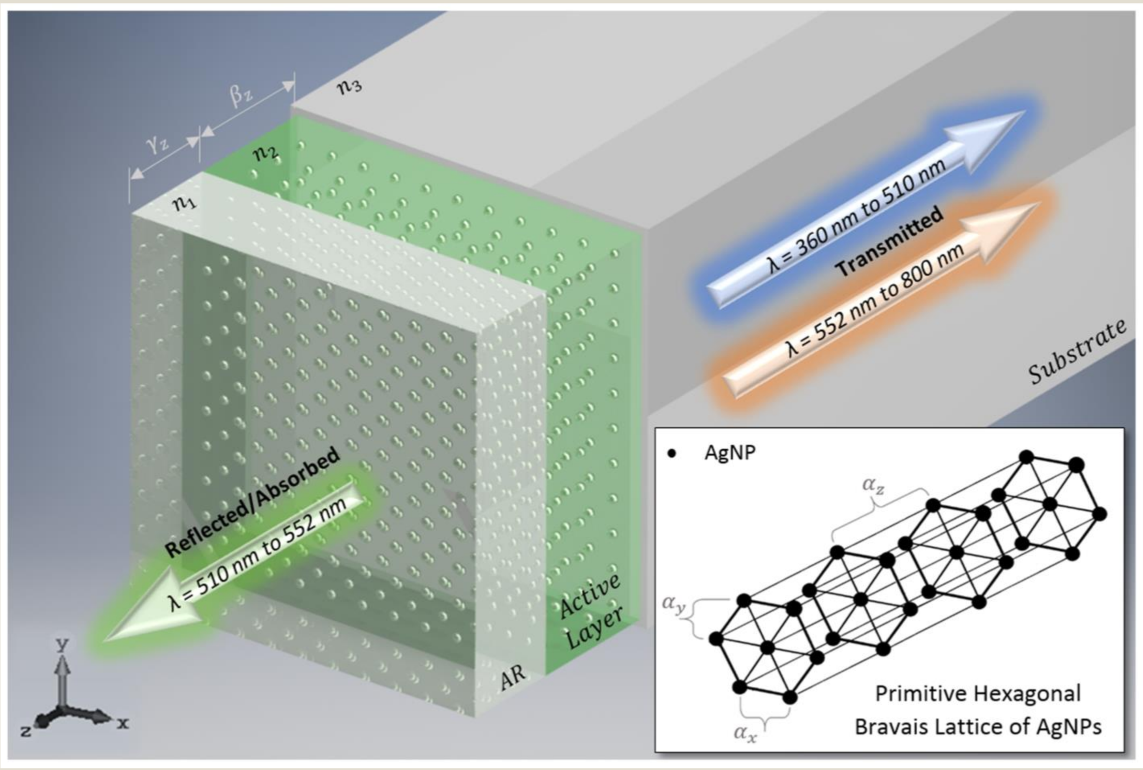

Fig. 5. Configuration of the 532 nm anti-laser device based on three-dimensional hexagonal planar array of AgNP as the active layer with $\alpha_x = \alpha_y = \alpha_z = \lambda_{laser}/16$; $\beta_z = 4\alpha_z$ and $\gamma_z = 3\alpha_z$. Insert shows the hexagonal lattice arrangement of the AgNPs within the 'active layer'.

Theoretical Optical Performance

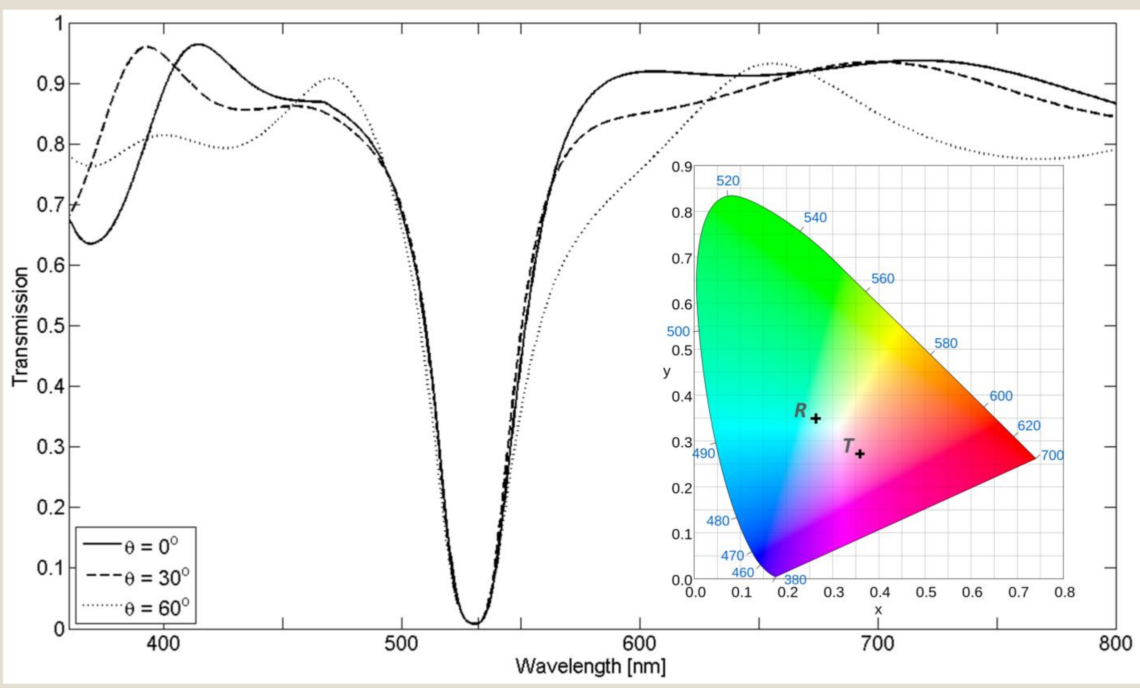

Fig. 6. Transmission of the three-dimensional optical metamaterial filter versus wavelength for incident angle at $\theta = 0^\circ$, $\theta = 30^\circ$ and $\theta = 60^\circ$. The solid, dashed and dotted lines denote the cases of the incident angle. Insert shows the CIE 1931 colour map for the transmission (T) and reflection (R).

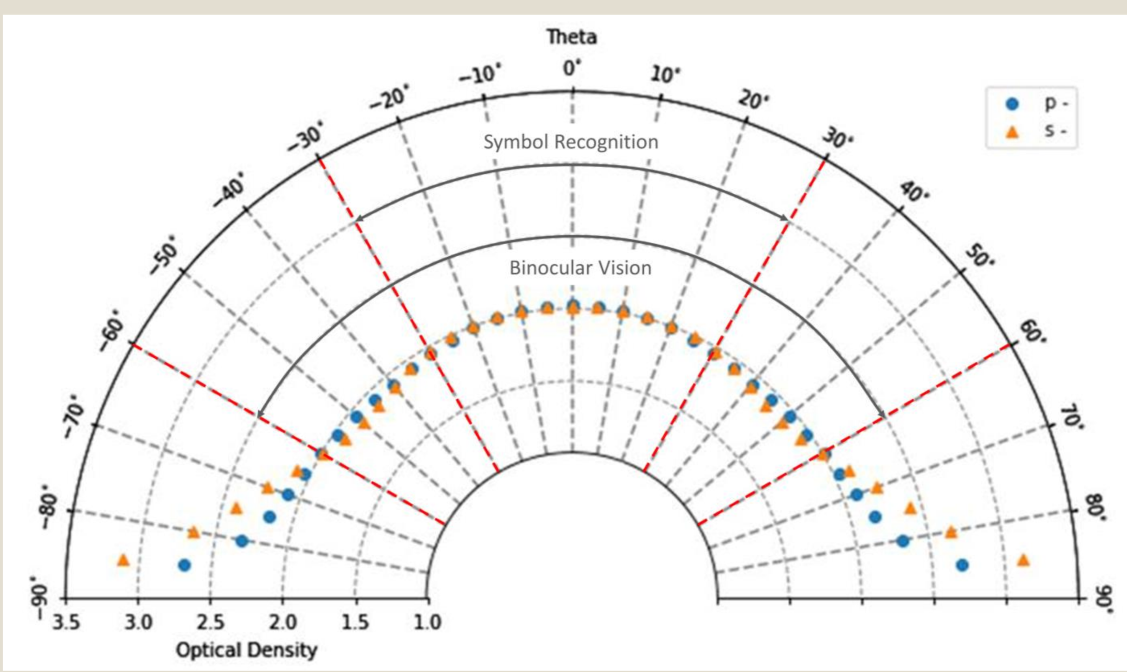

Fig. 7. OD of the designed filter at the laser wavelength of 532 nm. The circle and triangle data points denote the transverse mode of the electromagnetic radiation. Theta represents the angle of incidence. The peripheral vision regions have been noted in accordance to theta.

Discussion for Fabrication

Manufacturing sub 10 nm structures on a complex three-dimensional plane presents several major challenges [3], especially when dealing with large area fabrication. Overcoming the diffraction limit that is experienced with conventional photolithography methods is now made possible with the introduction of block co-polymers (BCP), which have gained significant attraction as a nanoscale self-assembling material . The unique ability of BCPs stems from the tendency to assemble discrete ordered morphologies at equilibrium over a large area. Utilising the ability of the BCP to achieve spot feature dimensions of sub 10 nm with a continuously uniform natural period separation could be a progressive move in the fabrication of the described laser protection design. The fabrication process can be enabled with material systems that include PS-b-PMMA, which can exhibit a high-order natural spacing length of 10 nm to 200 nm depending on the annealing process. Two-dimensional periodic and symmetric metasurfaces has previously been demonstrated and reported by Ju Young Kim et al. in 2016, where it was successfully demonstrated that a large area assembly of structured plasmonic materials using block copolymer self-assembly method was possible [4]. Moving towards a three-dimensional array can be achieved with multi-layer thin film BCP's, and would empower the next generation of complex optical metamaterials for various applications.

Conclusion

Our work explores the advancement of the next generation of laser protection devices and offers a design that is able to block a 532 nm laser, with an optical density of 1.88+. An additional function to this design is its ability to support multiple polarising laser blocking. The filter is designed using a metamaterial concept, where the active band rejection component is of repeated structures much smaller than the wavelength of interest. The considerable advantage to this filter design is the ability to rejects the lasing wavelength at all angles of incident whilst remaining shift-free, unlike the traditional optical thin-film laser protection coatings. Higher optical density can be achieved at the expense of a wider broadband to block pulsed and higher power CW lasers. The transmission of the design from a human's visual perception is ~61%, with an overall filter spectral transmission of 78%. This research offers a promising avenue for future high-performance laser protection systems that could be used in a wide variety of industries.

References

[1] UK Civil Aviation Authority, "Laser Incidents reported to the UK CAA 2017", *caa.co.uk*, 2017.
[2] UK Civil Aviation Authority, "Laser Incidents reported to the UK CAA 2016", *caa.co.uk*, 2016.
[3] X. Zhang, C. Sun and N. Fang, "Manufacturing at Nanoscale: Top-Down, Bottom-up and System Engineering", Journal of Nanoparticle Research, vol. 6, no. 1, pp. 125-130, 2004.
[4] J. Kim, H. Kim, B. Kim, T. Chang, J. Lim, H. Jin, J. Mun, Y. Choi, K. Chung, J. Shin, S. Fan and S. Kim, "Highly tunable refractive index visible-light metasurface from block copolymer self-assembly", Nature Communications, vol. 7, p. 12911, 2016.

This work has been published in Optical Communications peer reviewed journal and more information of the work can be found:

J. Monks, L. Yue, B. Yan, B. Aldred, A. Hurst and Z. Wang, " A wide-angle shift-free metamaterial filter design for anti-laser striking applications", *Optical Communications*, vol. 429, pp. 53-59, 2018.

Contact Information & Acknowledgments

The authors acknowledge the financial support provided by Knowledge Economy Skills Scholarship (KESS2, Ref: BUK289), Wales, United Kingdom, and from Sêr Cymru National Research Network in Advanced Engineering and Materials (NRNF66 and NRN113), Wales, UK.

James Norman Monks j.n.monks@bangor.ac.uk
Zengbo Wang z.wang@bangor.ac.uk