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Adaptive Surrogate Modelling-based Topology Optimization of colour splitting structures for high quantum efficiency CMOS image sensors

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Pixel scaling trend on CMOS image sensor (CIS) is approaching the range of 1.0 μm, and this is placing a practical limit with repect to the signal-to-noise ratio of detected signals [1]. To overcome such an inherent physical constraint, one can take an optical route to efficiently redistribute incident light energy by incorporating properly designed sub-wavelength scale photonic structures.

An attempt by Panasonic to replace conventional color filters with color splitting structures is noteworthy in this regard [2]. The performance of the demonstrated device, however, was far from the quality required for commercial products. Samsung Electronics recently proposed a novel approach to innovate current optical stack layer by designing color splitting photonic structures to more efficiently manipulate incoming light, resulting in highly enhanced quantum efficiency along with equivalent color reproduction quality [3]. However, the design strategy mainly relies on the parametric approach that is subject to the predefined topological design concepts based on physical intuition.

This paper presents a color splitting photonic structure driven by topology optimization based on an adaptive surrogate modelling to achieve high quantum efficiency. To formulate this design problem as a refractive index distribution problem, the design space is discretized by a 10-by-10 finite element mesh. Design variables are refractive index assignments in each discretized element, taking binary values of either 0 or 1 representing low refractive index (surrounding medium) or high one (color splitter), respectively. Since the light absorption spectrum is a good approximation of device quantum efficiency, the performance index is defined as the expected absorption spectra which are calculated by finite-difference time-domain method. To ease the computational burden, a Gaussian process (GP) with the binary representation like genetic algorithms (GAs) is used as a surrogate model. For GP with the binary representation, the Tanimoto similarity metric is used as a covariance function. In addition, the adaptive sampling method for optimization is based on the notion of expected improvement.

The results of applying the proposed method to design of a color splitting photonic structure for high quantum efficiency are demonstrated. During optimization process, it was found out that several design concepts based on physical intuition were local minimum and optimal topology was beyond our expectation.

The proposed method provides structural designers as well as optical device engineering professionals with a time-efficient alternative for topology optimization, which is beyond the reach of physical intuition or designers’ experience.

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