Robust Flat Optics for Broadband Light Control on Flexible Substrates

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Abstract: We present a platform for the inverse design of flat optics that are robust to fabrication errors and mechanical deformation. Experimentally, we show flexible polarizers that maintain 80% efficiency when curved over a 200 nm bandwidth.

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Main Text

Flat optics is a promising light manipulation technology that aims to replace conventional bulk optics with nanostructured surfaces with equivalent or improved functionality [1]. Numerous applications of this technology have been demonstrated in imaging [2], optical communications [3], energy harvesting [4], and optical computing [5]. Presently most flat optics designs are produced on rigid substrates, such as glass or quartz [6]. This allows exploiting well established nanoscale fabrication techniques borrowed from the semiconductor industry but limits the application of flat optics on curved surfaces and on soft biocompatible substrates [7]. Addressing these limitations has spurred research into the field of flexible flat optics in recent years [8]. An important challenge in flexible flat optics is ensuring the performance of a design does not degrade significantly upon deformation. Deviation from the ideal geometry of a design can cause performance drops of over 50%, as recent research on gold nanorods has shown [9]. In this work we present an inverse design platform that addresses this issue, enabling the fast design of flexible flat optics that are robust to deformations of their geometry.

In a previous work we introduced ALFRED, an inverse design platform based on the generalized scattering theory [10] that couples a global parallel optimizer with a neural network predictor unit to obtain high efficiency flat optics [11]. Here we extend the capabilities of this platform through the development of a deep learning based spectral predictor, which allows evaluating the spectral response of standard and deformed designs in a timescale of milliseconds. We employ the predictor to design samples robust to fabrication errors and deformations by following a statistical approach based on weighted least-squares. Starting with an un-deformed design geometry as the base, our platform produces hundreds of randomly perturbed versions of the design in which the dimensions of the resonators and their separation are varied by tens of nanometers. The platform then seeks the design that best retains the desired optical response against these deformations.

To validate our methodology we designed, fabricated, and tested two broadband polarizers for operation on a 200 nm bandwidth centered at 700 nm. One of the designs was optimized for robustness to deformations, while the other was not. The polarizers were fabricated through the patterning of a layer of amorphous silicon deposited on a polyimide tape substrate to make them flexible. Fig. 1a shows a photograph of one of the finalized samples, while Fig. 1b shows a scanning electron microscope (SEM) image of the produced pattern. The performance of the samples against deformation was determined by measuring the polarization efficiency of each fabricated design when flat and at various radii of curvature of circular deformation. Fig. 1c shows the result of these measurements. The robustly designed sample presents almost constant performance, showing a variation of less than 3% in its polarization efficiency. At odds with this, the non-robust design performance is seen to drop significantly when it is deformed, presenting a 53% decrease in performance for the tightest curvature condition. The results are consistent with the predictions of the platform shown in Fig. 1d, where the robust design is seen to maintain high performance when subjected to most alterations of its geometry, in contrast to the performance drops of the non-robust design.

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Fig. 1. **a** Photograph of a completed flexible polarizer sample. **b** SEM micrograph showing the nanoscale structure of the device in **a**. **c** Relative increase/decrease of the bandwidth averaged polarization efficiency for robust (blue) and non-robust (orange) samples when deformed to different radii of curvature r . **d** Probability density function of the averaged polarization efficiency for robust (red) and non-robust (blue) simulated designs when deformed.

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