Design and Implementation of a Flat-Focal-Field Arrayed Waveguide Grating on a Si_3N_4 Platform

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***Abstract*— We present the design and implementation of a flat-focal-field arrayed waveguide grating, which solves the non-flat focal surface problem in Rowland AWGs. This design can accommodate a butt-coupled detector array positioned at the output without any reduction of the resolving power for the edge channels.**

Keywords—astrophotonics, arrayed waveguide grating, flat focal field

I. INTRODUCTION

The major objective of the emerging field of astrophotonics is the miniaturization of next-generation astronomical instrumentation by leveraging the integrated photonics platform. To probe the first billion years of the universe, an integrated astrophotonic spectrograph is proposed [1], which uses an arrayed waveguide grating (AWG) as the light-dispersing component. To separate the overlapping spectral orders and obtain a full 2D spectrum, it is necessary to have the chip cleaved for cross dispersion and imaging onto a flat detector array. However, this imposes a challenge on the traditional Rowland AWGs in which the focal surface is a circle. If a Rowland AWG is cleaved along the tangent of the circle, as illustrated in Fig. 1(a), the offset (marked by the red arrows) between the focal point and the cleaving line will give rise to a defocusing aberration for all channels except for the central one. Thus, a flat focal plane is desired to minimize the defocusing aberrations for the edge channels.

In this abstract, we present the design and implementation of a flat-focal-field AWG based on the aberration theory proposed in Ref. [2]. The flat focal plane of this non-traditional AWG addresses the defocusing aberration for the edge channels when the device is cleaved along the focal plane.

II. THEORY AND DESIGN

A detailed discussion of the aberration theory can be found in Ref. [2]. As a brief summary, an optical path function $F(w)$ is defined to describe the light propagation in an AWG: $F(w) = n_s r_A(w) + n_w L(w) + n_s r_B(w) - G(w)m\lambda$, where n_s and n_w are the effective indices of the slab mode and guided mode, $r_{A/B}(w)$ is the distance from I/O waveguides to one of the array waveguides determined by the grating curve $u(w)$. $L(w)$ and $G(w)$ describe the length and location of the array waveguides, and m is the grating order. $F(w)$ can be expanded into a Taylor series, and the coefficient $F^{(n)}(0, \lambda)$ is referred to as the n^{th} aberration coefficient.

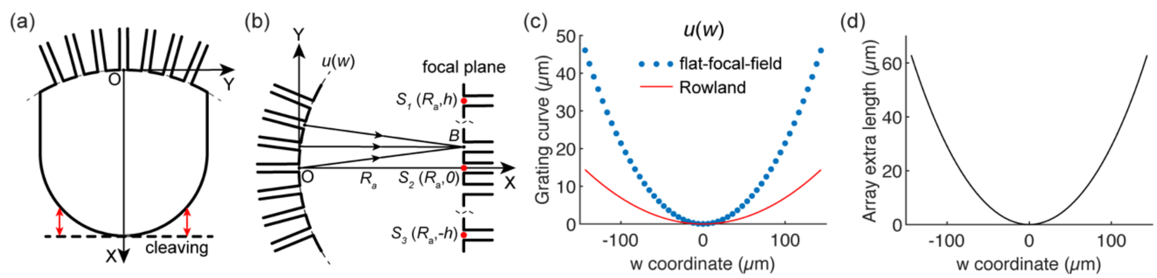

Fig. 1. (a) Defocusing aberration (red arrows) when the AWG is cleaved. (b) Flat focal plane defined by the three stigmatic points S_1, S_2, S_3 (red). (c) Calculated grating curve of the designed flat-focal-field AWG (blue) compared to the corresponding Rowland AWG (red). (d) Calculated extra length of the array waveguides.

The three parameters $u(w)$, $L(w)$, and $G(w)$ in the optical path function can determine the structure of an AWG, indicating that a total of three constraints can be imposed. For a traditional Rowland AWG, these constraints are: (1) the grating curve $u(w)$ is an arc, (2) the array waveguides are uniformly spaced along the grating curve and (3) the length difference between adjacent waveguides

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in the array is a constant. For a flat-focal-field AWG, these three constraints are: the aberration coefficients $F^{(n)}(0, \lambda_i)$ at the three stigmatic points S_i (i = 1, 2, 3) [as shown in Fig. 1(b)] vanish. The three stigmatic points are colinear to define a flat focal surface.

By solving the set of three equations $F^{(n)}(0, \lambda_i) = 0$ up to the desired order, the structure of a flat-focal-field AWG can be determined. Here we design a flat-focal-field AWG with 21 output channels and 51 array waveguides on a 100 nm Si_3N_4 platform. Fig. 1(c) and 1(d) show the calculated grating curve $u(w)$ and the extra length of the array waveguides. In this case, the grating curve is no longer circular, the array waveguides are no longer uniformly spaced, and the length difference is no longer a constant. A comparison of the star couplers of a Rowland and the corresponding flat-focal-field AWG is plotted in Fig. 2.

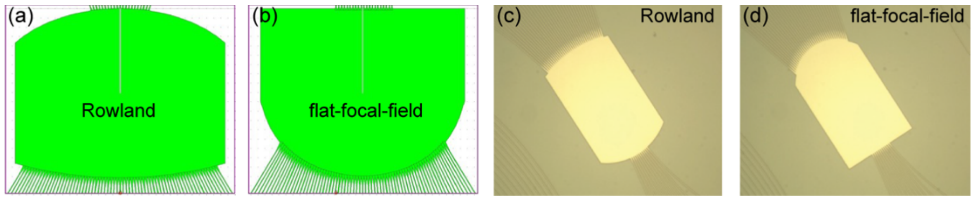

Fig. 2. Star couplers of the (a) Rowland and (b) flat-focal-field AWGs in RSoft. Microscope images of the fabricated (c) Rowland and (d) flat-focal-field AWGs.

III. Simulation and experimental results

The spectrum simulation of the designed flat-focal-field AWG is completed jointly by Synopsys RSoft and Matlab. Since the built-in simulation utility in RSoft only supports the simulation of Rowland AWGs, a Matlab script is developed for the automation of the spectrum scanning process. An important figure-of-merit to look for is the spectral resolving power, defined by $\lambda/\Delta\lambda$ for a specific channel. Simulation and experimental results of the designed flat-focal field AWG, together with the corresponding Rowland AWG, are plotted in Fig. 3. Comparisons of the simulated and measured resolving powers of the two AWGs are also included.

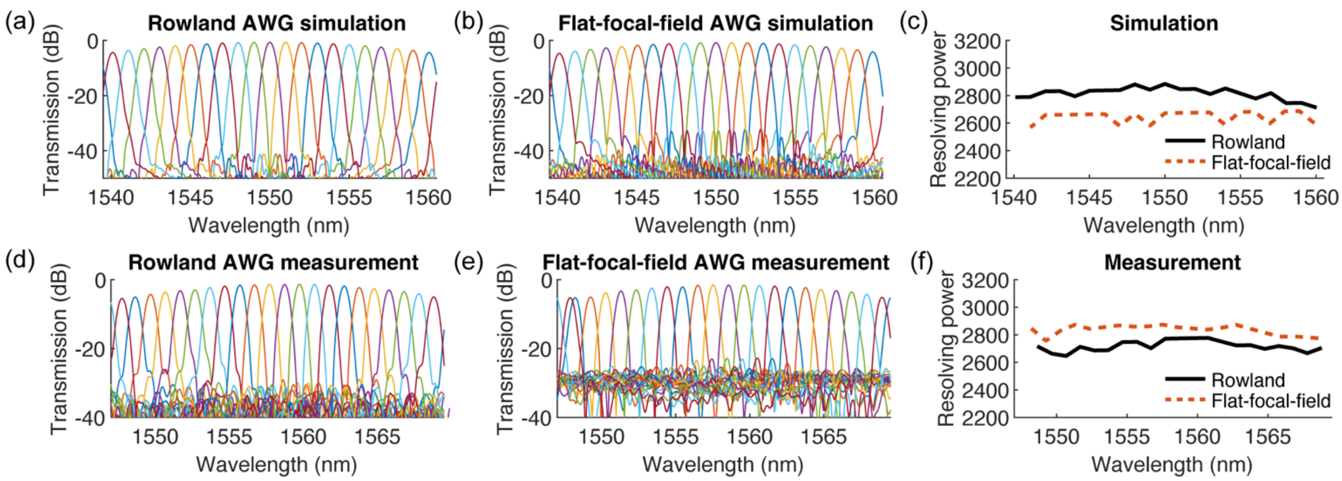

Fig. 3. Simulated transmission spectra of the (a) Rowland and (b) flat-focal-field AWGs. (c) Comparison of the simulated resoving power of the two AWGs. Measured transmission spectra of the (d) Rowland and (e) flat-focal-field AWGs. (f) Comparison of the measured resoving power of the two AWGs.

We conclude that: (1) a good agreement between the experimental and simulated spectra has been achieved, and (2) the resolving powers of the two AWGs are very similar within the uncertainties of the measurements (± 5%). These experimental results confirm that the output focal plane is flattened as intended. We also notice that the channel spacing of the fabricated flat-focal-field AWG is slightly wider [indicated by the two closely spaced channels in Fig. 3(e)], which can be addressed by a slight adjustment of the position of the output focal surface.

IV. Conclusion

We have presented the design and implementation of a Si_3N_4 flat-focal-field AWG. Due to the flat focal plane of this design, the defocusing aberration of the edge channels is minimized and the resolving power of the edge channels is improved. This design provides a solution for a flat-focal-field spectrometer, which fulfills the requirement of an integrated astrophotonic spectrograph in which the chip needs to be cleaved along the output focal surface of the AWG.

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