EVERIX

OPTICAL FILTERS DRIVING INNOVATION

Angular Shift Compensation in Thermoformed Curved Thin-Film Interference Optical Filters

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Summary

Optical interference filters have an inherent blue shift at increasing angles of incidence (AOI). This angular shift leads to undesired constrains in optical sensor design. Curved filters can compensate such an angular shift considerably, enabling sensor designers to tighten the bandpass filter’s bandwidth and improve signal to noise ratio (SNR) without compromising the field of view. This becomes possible since the optical filters are manufactured like optical fibers, i.e. fundamentally different from conventional material deposition.

Introduction

Interference filters exhibit a strong effect of angle-of-incidence (AOI) on spectral performance, as described in Equation 1. Spectral features shift to lower wavelengths and edge slopes become less steep. This can cause issues, especially in applications where the filter is placed in a position of a strongly converging or diverging beam (as in many small-f/# applications).

Equation 1

$$\lambda_\theta = \lambda_0\sqrt{1-\left(\frac{n_0}{n_{eff}}\sin\theta\right)^2}$$

Where:

- λ_θ = wavelength corresponding to the feature of interest at incident angle θ
- λ_0 = wavelength corresponding to the feature of interest at normal incidence
- n_0 = refractive index of incident medium
- n_{eff} = effective refractive index of the optical filter
- θ = angle of incidence

Everix interference filters are prepared using a novel hot-drawing or stretching process of a polymer preform (Figure 1). The process induces some mechanical differences in directions parallel and perpendicular to the draw direction. We will investigate the effects of curving in both parallel and perpendicular directions. Further, interference filters are extremely sensitive to thickness variations in the individual layers that make up the filter stack. Bending the filter introduces compressive stress on the inner layers (perhaps increasing their thickness) and tensile stress on the outer layers (perhaps decreasing their thickness) perhaps altering the performance. This will also be investigated.

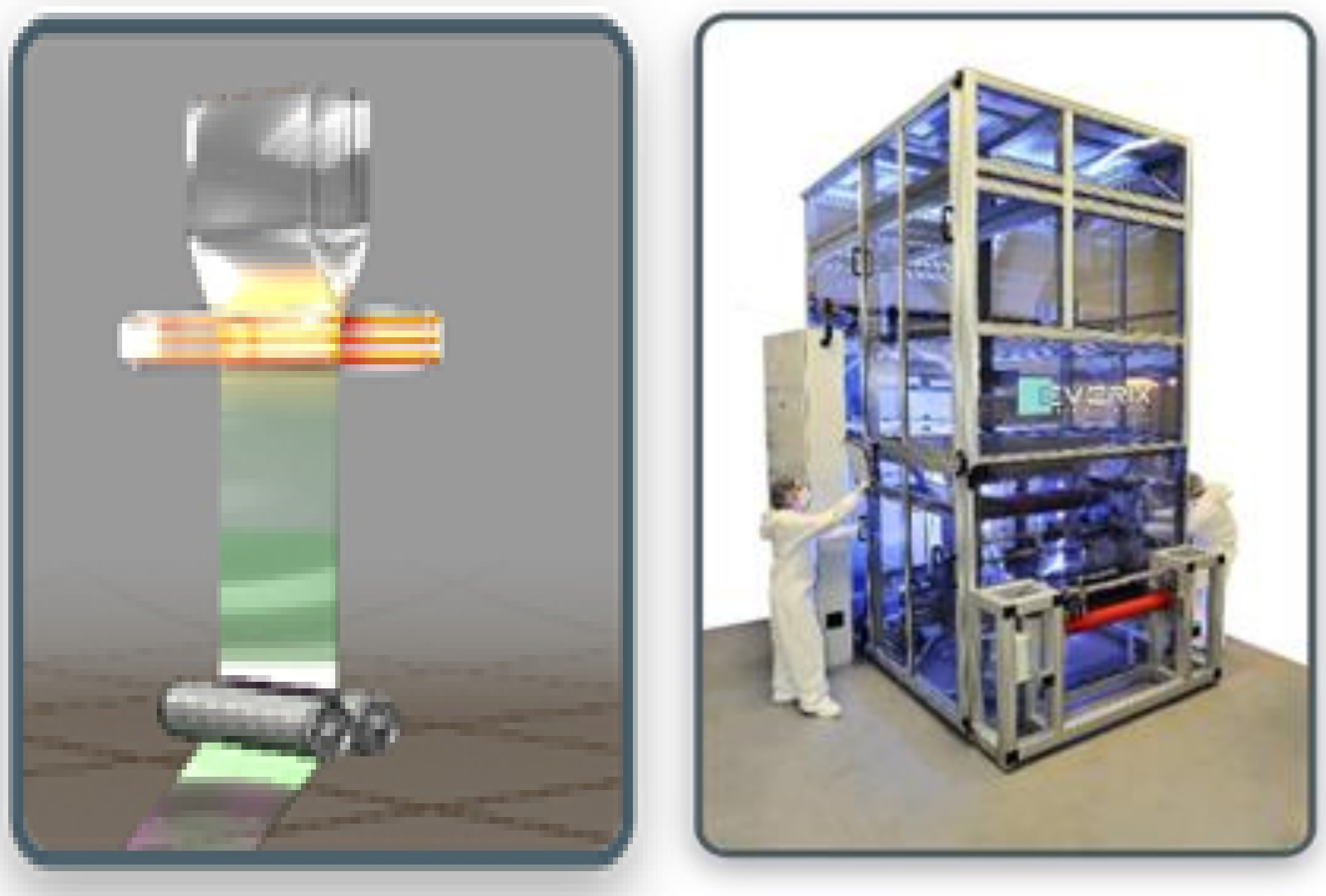

Figure 1.
Left – Schematic of the thermal draw process
Right- The custom draw tower designed and operated by Everix

Methods

We utilized a fiber-coupled light source with a 5 mm beam diameter as a source with a StellarNet fiber-coupled spectrometer with 0.5 nm resolution in the visible spectrum. A schematic of the setup is shown below (Figure 2, left). The samples were rotated about their center of curvatures. The flat sample was positioned at the center of rotation of the system. To maintain a similar illumination area for different radii of curvature, we used apertures to keep the illuminated area approximately 5 degrees in the curved samples. To account for spectral inhomogeneities in the films, normal-incidence translated scans were also acquired and used as the reference for the curved data. Measurements were made with the rotation and slits positioned parallel and perpendicular to the draw direction as in Figure 2 (right).

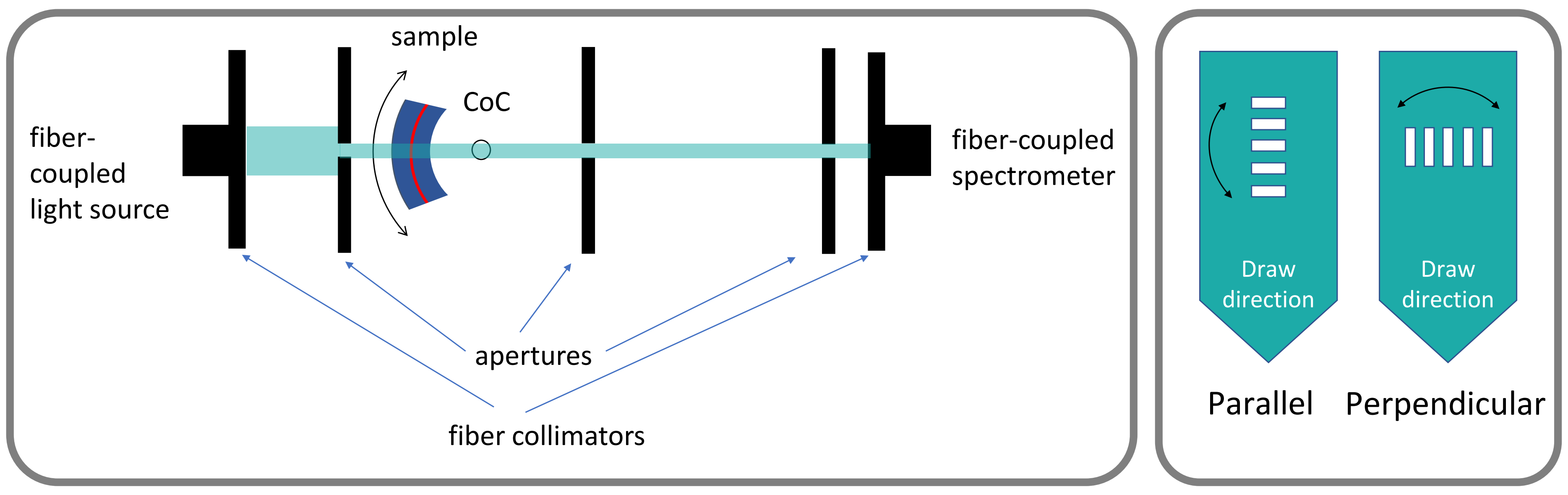

Figure 2. (Left) Schematic of the optical system used for these experiments and (Right) sample geometries

Results

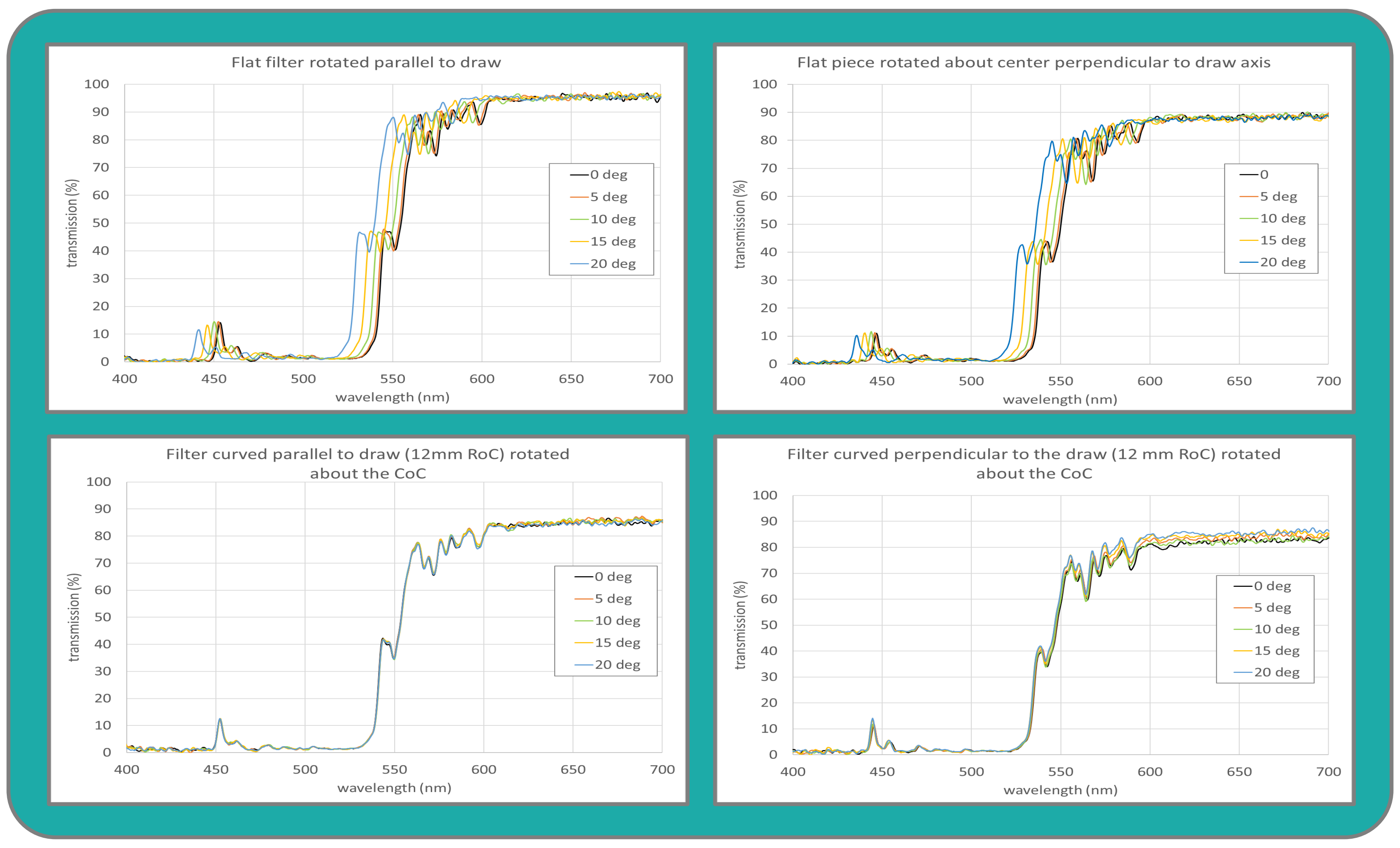

Figure 3. Rotating a flat filter (top) and curved filters (bottom) parallel (left) and perpendicular (right) to the draw axis. The flat filter exhibits a large wavelength shift. There is no notable difference between the parallel and perpendicular directions.

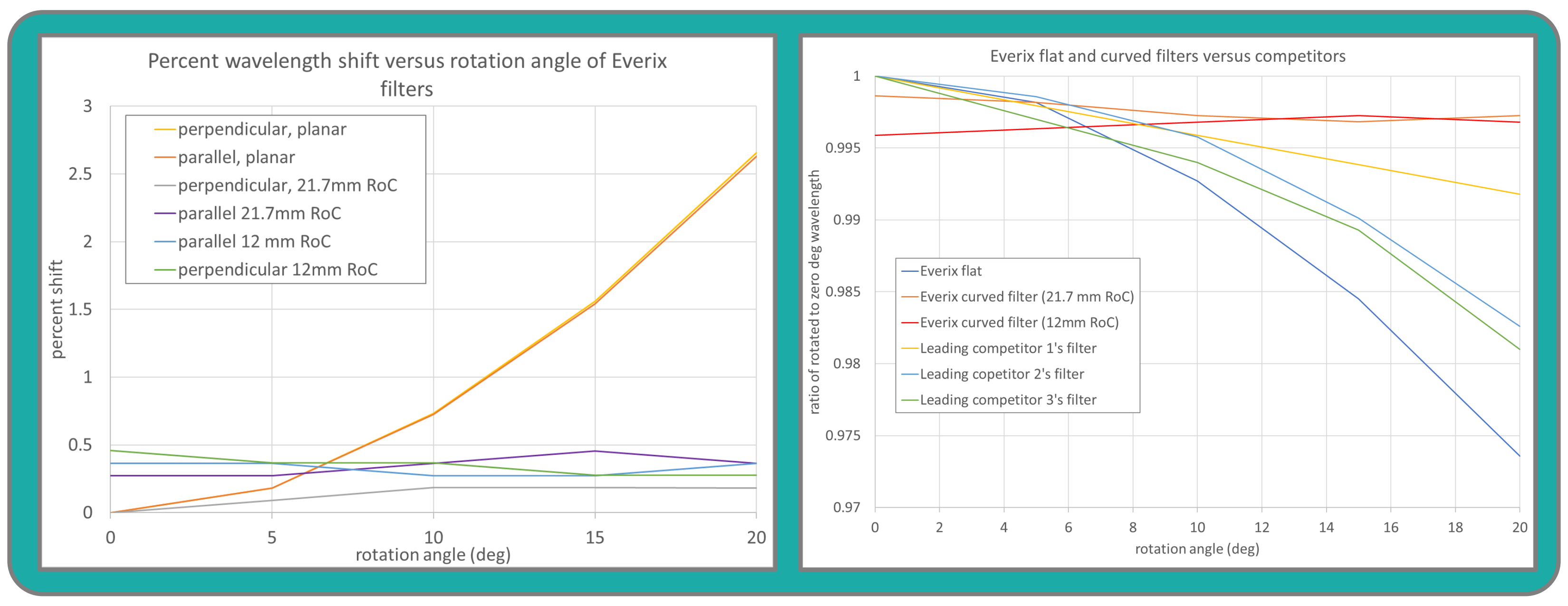

Figure 4. Left- percent shift observed as a function of rotation angle for flat and curved filters. Right- Ratio of average wavelength shift versus normal incidence for flat and curved Everix filters versus competitors. We do not observe any angular shift in the curved filters within our measurement capabilities.

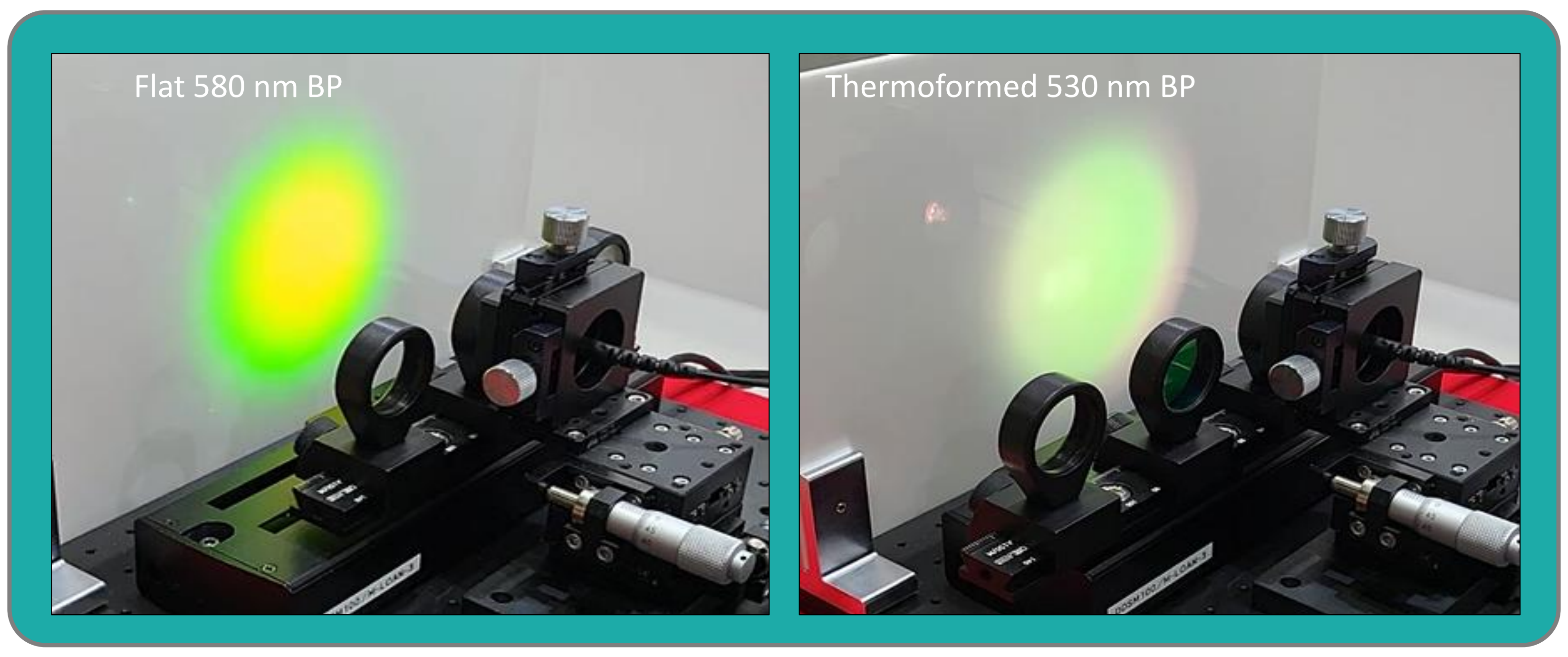

Figure 5. Qualitative data showing the performance of a thermoformed filter illuminated from the center of curvature (Right) versus a flat filter (Left). Note that these bandpass filters are centered at different wavelengths. The color is much more uniform in the case of the thermoformed filter.

Discussion and Conclusions

Within the error of our system (positioning, angle measurement and spectral resolution), we do not observe any shift in wavelength when the filter is rotated around its center of curvature. We also do not observe any different behavior when the filters are curved parallel or perpendicular to the draw direction. This work can be extended into 3 dimensions as illustrated with the thermoformed results in Figure 5. Everix is currently in the process of optimizing the thermoforming process to provide filters with nearly any 3-dimensional shape. The ability to match the filter to the wavefront of the system will open new optical design methods.

Compared with other filters on the market (Figure 4 Right), our filters show a similar spectral shift in the flat configuration but provide much better performance compared to competition when curvature is incorporated into the optical design. This capability will reduce or eliminate angular shifts in the filters, increase signal-to-noise and blocking in systems and enable unique system designs.

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