“The color of a flower field changes with a butterfly’s flight vector” is a metaphor for homochirality colorimetry via chiral nanostructure arrays

Zaid Haddadin[1], Anna My Nguyen[2], Paula Kirya[2], Lisa V. Poulikakos[2,3]

1. Electrical & Computer Engineering, University of California San Diego, La Jolla, CA 92093
2. Mechanical & Aerospace Engineering, University of California San Diego, La Jolla, CA 92093
3. Program of Materials Science & Engineering, University of California San Diego, La Jolla, CA 92093

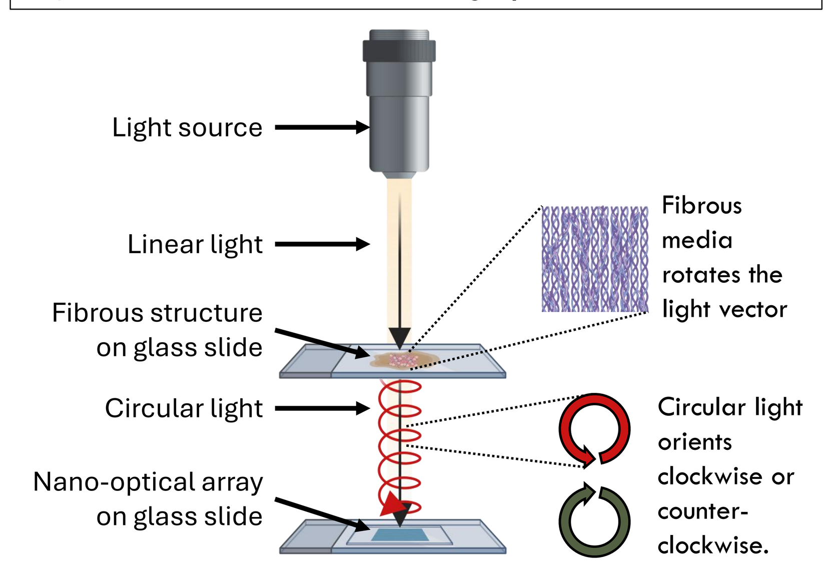
Introduction

Fibrous or filamentous biological structures, like microbial mats, can rotate a light wave’s travel vector [1,2]. However, this rotation is too minimal to measure without meter-scale tools [3]. **This work explores miniaturizing these tools to the nanometer level for *in-situ* applications.**

One possibility is rotating a light vector into a circular path, either clockwise or counter-clockwise [3]. Homochirality is when an orientation of circular light is favored over the other [3,4,5]. **Detecting homochiral light is an agnostic biosignature of life** [5].

We investigate how this biosignature could be detected using arrays of nanoscale particles. By using visible light, our optical arrays also act as colorimetric sensors of homochirality [3,6,7].

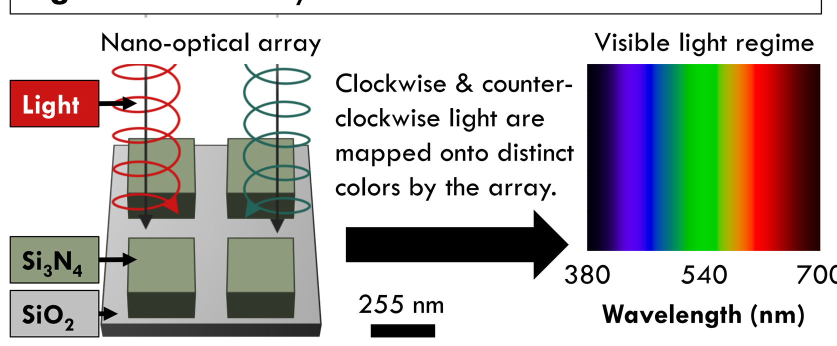
Figure 1: Schematic of sensing system.



Materials and methods

We investigate how a cut to one corner of square- and rectangle-shaped nanostructures affects their sensitivities to differentiating between incident clockwise or counter-clockwise oriented circular light.

Figure 2: Summary of methods.



Results

- Differentiation of clockwise and counter-clockwise polarization states of circular light was achieved.
- Squares: **Figure 3** shows cuts to the square structure affect the reflectance response but result in non-differentiable outputs. **Table 1** displays the non-differentiable colorimetry results. **Figure 4** examines the near-field response: cuts simplify the problem from a quadrupole to a dipole, which dampens the reflectance response due to a decreased energy output.
- Rectangles: Simplifying the problem in rectangles from four nodes to two nodes extinguishes the longer-wavelength reflectance peaks, as shown in **Figure 5**’s “Medium Cut” group. This unequally dampens the shorter-wavelength peaks of the two polarization states. Both these observations contribute to the differentiable colorimetry results in **Table 2**.

Figure 3: Applying cuts to a square-shaped nanoparticle

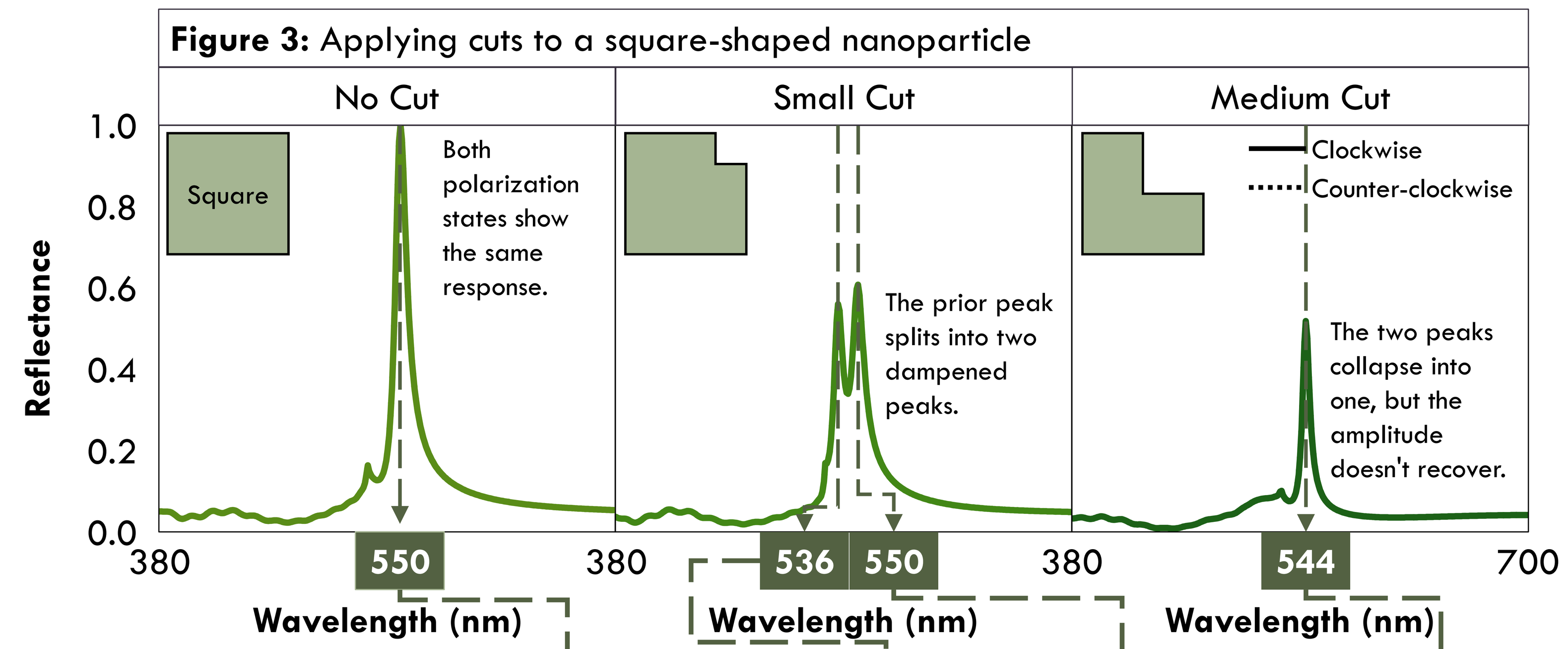


Table 1: Colorimetry results from Figure I reflectances.

	Clockwise	Counter-clockwise
No Cut	#598C18	
Small Cut	#428716	
Medium Cut	#1C6117	

Figure 4: Near-field plots

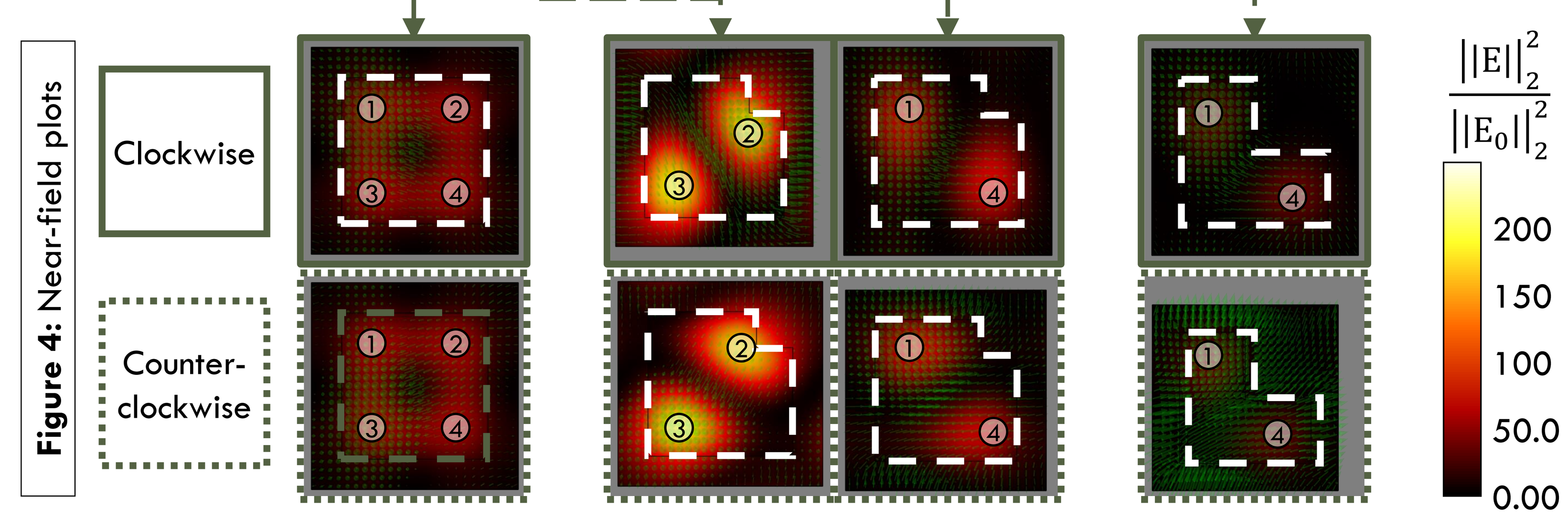


Figure 5: Applying cuts to a rectangle-shaped nanoparticle

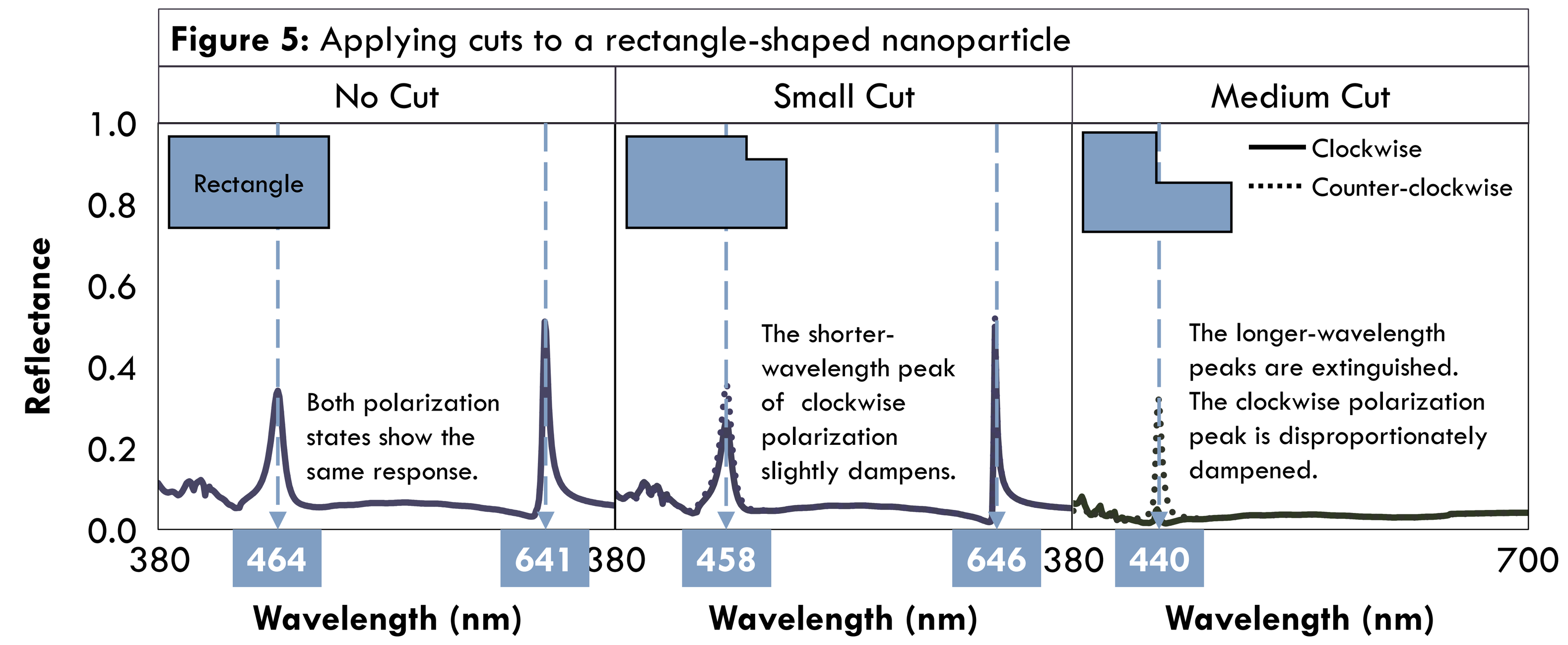


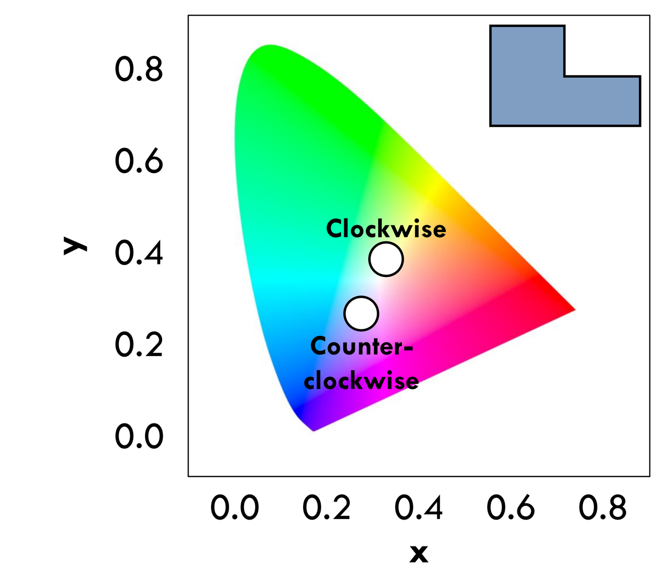
Table 2: Colorimetry results from Figure III reflectances.

	Clockwise	Counter-clockwise
No Cut	#484564	
Small Cut	#424059	#433F62
Medium Cut	#31352A	#343146

Conclusions

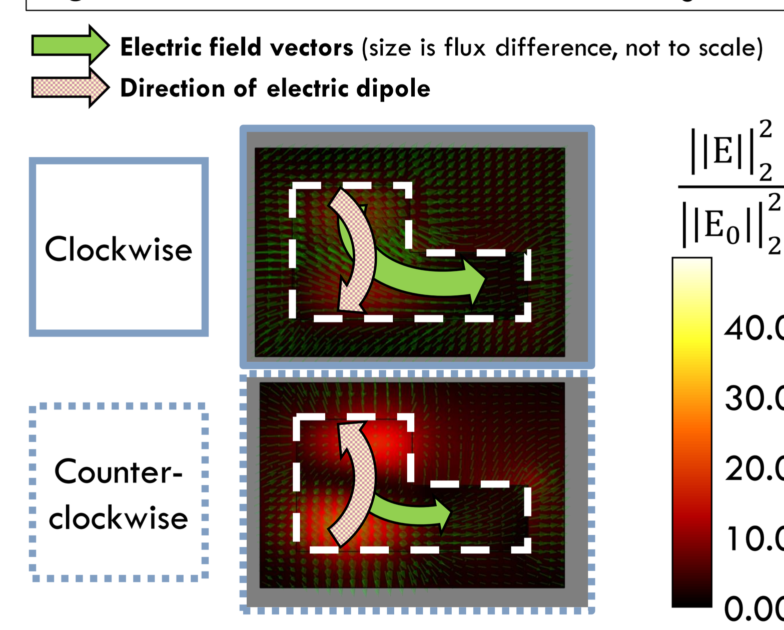
Biological media with fibrous structures can alter light polarization, an agnostic indicator of life [1,2]. **Designing nano-optical arrays enables miniaturized optical sensors for polarized light, which may be useful for *in-situ* investigations.** Our study showed that nano-optical arrays can differentiate clockwise and counter-clockwise circularly polarized light, **allowing colorimetry homochirality detection** (see **Figure 6**).

Figure 6: Colorimetry using medium-cut rectangles.



However, the reason for this remains unclear. **Figure 7** suggests that under clockwise light, the dipole charge aligns with the sideways flux, reducing light reflected towards the imaging apparatus. Under counter-clockwise light, the dipole charge opposes this flux. This could explain the disproportionate dampening in reflectance and the distinct colorimetry results.

Figure 7: Near-field of medium cut rectangle.



Literature cited

1. Ghosh N, Wood MFG, Li S hong, Weisel RD, Wilson BC, Li RK, et al. Journal of Biophotonics. 2009;2(3):145–56
2. Sparks WB, Parenteau MN, Blankenship RE, et al. Astrobiology. 2021 Feb;21(2):219–34.
3. Kwon J, Park KH, Choi WJ, et al. Acc Chem Res. 2023 Jun 20;56(12):1359–72.
4. Avnir D. New Astronomy Reviews. 2021 Jun 1;92:101596
5. Neveu M, Hays LE, Voytek MA, et al. Astrobiology. 2018;18(11):1375–402.
6. Haddadin Z, Khan S, Poulikakos LV. ACS Photonics. 2024 Jan 17;11(1):187-195.
7. Fairchild MD. Color Appearance Models. John Wiley & Sons. 2005; 2nd Ed.

Acknowledgments

Research funding received through the UC San Diego MRSEC Seed Grant and from the Arnold and Mabel Beckman Foundation. Travel funding from AbGradCon24.

Thank you to Julia Holland for brainstorming the presentation’s title, and to the rest of my coworkers in the Poulikakos Lab for the research discussions and continued support ☺

Further information

I’m at zalhadda@ucsd.edu for further questions & discussions. Scan the below QR code for a PDF copy of this poster.

UC San Diego JACOBS SCHOOL OF ENGINEERING

POULIKAKOS LAB

ABGRADCON24 CORNELL UNIVERSITY