# Evaluating and Designing Metasurfaces for Exciting Skyrmions in 2D Materials

Sophia Ellis[1,2], Mohammadali Khosravi[2], Yuxuan Hu[1], Dr. Yanwen Wu[2], and Dr. Mariama Rebello de Sousa Dias[1]

1: University of Richmond, Department of Physics, 138 UR Drive Richmond, VA 23173
2: University of South Carolina, Department of Physics and Astronomy, 712 Main Street Columbia, SC 29208

## Abstract

The nature of this research is to design nanostructures that will excite and control skyrmions on two-dimensional materials. Using the experimental method of thermal lithography, we created nanodisks with a 50 nm radios in a hexagonal array of a period of 120 nm. When excited with circularly polarized incident light, the Inverse Faraday Effect (IFE) creates opposite propagating currents inside each unit cell. This method has the potential to excite Néel-type magnetic skyrmions.

## Skyrmions

Skyrmions are a hot topic in condensed matter physics. Magnetic skyrmions, the more well-known type, are vortex structures that occur in magnetic materials, characterized by the spin of the electrons. They have promising applications in high-density information storage. More recently, an optical counterpart to the magnetic skyrmions was discovered. Optical skyrmions are characterized by the polarization of the photons and require being able to control light at the nanoscale. These have many applications including:

- High-precision positioning
- Density storage
- Optical communication

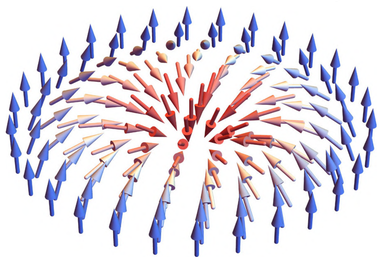


Fig. 1. Vector field of a Néel-type skyrmion.

This project focuses on understanding the generation of optical skyrmions by the Inverse Faraday Effect.

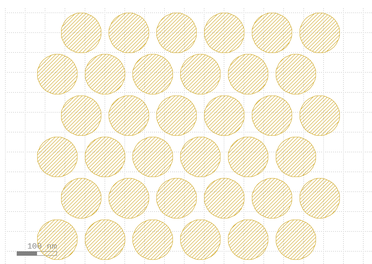



Fig. 2. Desired pattern for metamaterial. 50 nm disks with a period of 120 nm.

We needed to create a metasurface of gold nanodisks in a hexagonal array to achieve this effect. When excited with circularly polarized light, we expect a skyrmion crystal to form on top of the disks.

## Thermal Lithography

Using NanoFrazor technology, we look to create a nanostructure with a resolution of 20 nm. The cantilever tip will heat up and etch into a polymer that acts as a mask to protect the glass substrate.

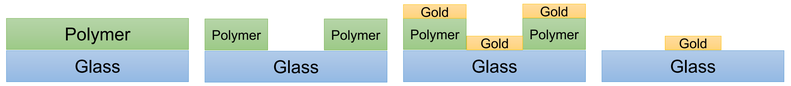



Fig. 3. Process of sample preparation including lithography, deposition, and lift-off.

After the etch, we deposit a thin layer of gold using electron beam evaporation to make the nanodisks. Then we lift off the polymer and unwanted gold film to achieve our vision.

## Patterning Results

To achieve such small nanostructures, we had to develop a diluted solution of PA25 to achieve a thickness of around 15-20 nm. We had to optimize many parameters to achieve this pattern:

- Temperature
- Forward Height
- Pixel Time
- Force Pulse

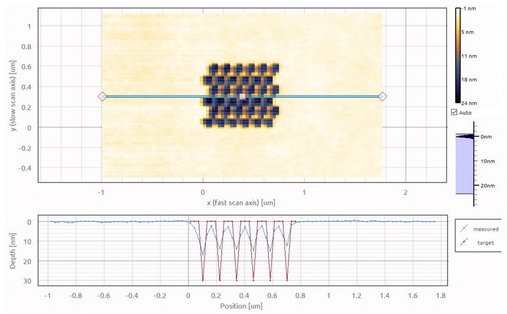



Fig. 4. Graph from NanoFrazor software of etch.

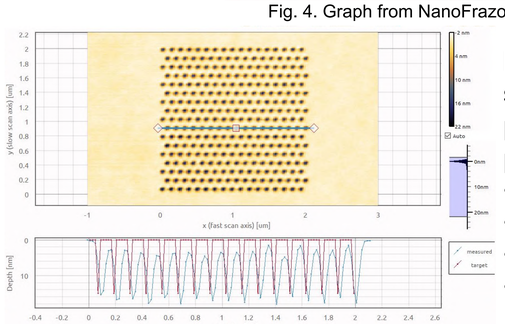



Fig. 5. Graph from NanoFrazor software of etch with better resolution .

Here we found more success with the pixelated method. The parameters are :

- 850 degrees Celsius
- 230 nm height
- 25 us pixel time
- 5 us force pulse

This process was difficult and lengthy as this lab had never created such small nanostructures, usually 2x this size.

## Simulation Results

Through Lumerical FDTD, we simulated this experiment to confirm results and better understand the methods of excitation.

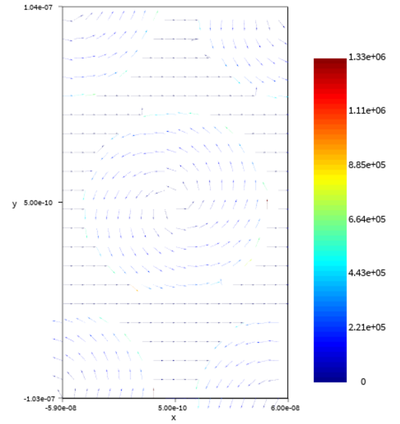
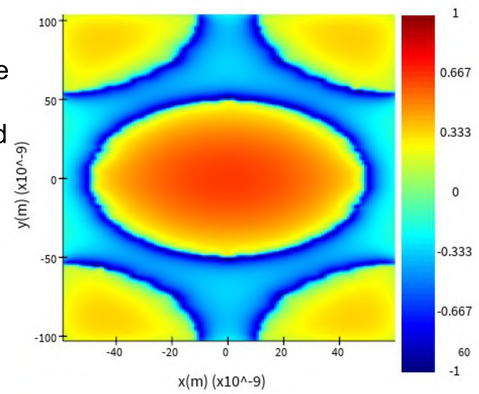



Fig 6. The drift current excited by circularly polarized light by the Inverse Faraday Effect. A counterpropagating current will result in the excitation for the Néel-type skyrmion.

Fig. 7. Here is the z-component of the magnetic field shows the formation of a Neel-type skyrmion.

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## Citations

Yang, Aiping & Kong, Aru & Meng, Fanfei & Chen, Xusheng & Lin, Min & Shi, Peng & Du, Luping & Yuan, Xiaocong & Wang, Biao. (2025). Optical skyrmions: from fundamentals to applications. Journal of Optics. 27. 10.1088/2040-8986/ada6d6.
Yang, Xingyu & Hareau, Chantal & Gartside, Jack & Mivelle, Mathieu. (2025). Light-Driven Skyrmion Crystal Generation in Plasmonic Metasurfaces Through the Inverse Faraday Effect. 10.48550/arXiv.2503.23800.