Shape Classification of Objects Too Small to See

S. Kurdiumov[1,2*], **J.-Y. Ou**[1], **N. Papasimakis**[1] **and N.I. Zheludev**[1,3]

[1] Optoelectronics Research Centre & Centre for Photonic Metamaterials, University of Southampton, Southampton, SO17 1BJ, UK
[2] School of Science and Engineering, University of Dundee, Nethergate, Dundee, DD1 4HN, UK
[3] Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore
*skurdiumov001@dundee.ac.uk

Classification of nanoscale objects is crucial in nanotechnology, biological and materials sciences. Non-invasive optical classification approaches (e.g. microscopy) are restricted by the diffraction limit, which does not allow to resolve objects smaller than half of the wavelength (λ/2). Here, we introduce a new method for the shape classification of deeply-subwavelength nanoscale objects. The method involves capturing the scattering pattern from an object of unknown shape and size in an optical microscope followed by neural network processing, which classifies the shape of the imaged objects. We show experimentally classification with accuracy of 87.6%.

In our proof-of-principle demonstration, we selected five different shape classes commonly present in nanotechnology and life sciences: triangle, ellipse, zigzag, cross, and Y-shape. Each shape class contained 243 objects, so that every object has unique combination of aspect ratio and size (in the range from 100 nm to 320 nm). Two scenarios were considered: the orientation of the objects in the field of view was either fixed or arbitrary. The objects were fabricated as apertures milled by focused ion beam in a 130 nm thick gold film deposited on a cover glass substrate.

The sample was placed in a conventional optical microscope and illuminated with a tightly focused linearly polarized laser beam (λ = 638.1 nm) with a spot size of 1 μm^2 (at $1/e^2$ level). The corresponding scattering patterns were collected at a distance of 2λ (1276.2 nm) from the sample plane by a high numerical aperture objective (NA=0.9) and recorded by a CCD camera. 80% of the resulting dataset together with the corresponding shape class labels was used to train a convolutional neural network (CNN), while the remaining 20% was used for testing.

In summary, we experimentally demonstrated a robust technique for shape classification of nanoscale objects of sizes down to 100 nm (λ/6.4). We show an accuracy of 87.6% for nanoscale objects commonly present in nanotechnology. We argue that our method will find applications in nanotechnology, the classification of viruses and non-destructive quality control applications, such as defect detection in the fabrication of semiconductors.