

NANOSCOPE: Superresolution without Evanescent Fields

This project aims to develop a revolutionary non-invasive optical imaging technology, the NANOSCOPE, which is based on the new concept of super-oscillation and will have numerous applications across the whole domain of scientific research. For the first time it will allow imaging and manipulation of objects inside a living cell with nano-scale resolution and the creation of truly sub-wavelength featured optical landscapes. Beyond biological applications, this project will impact all types of imaging and lithography technologies. www.nanoscope.org.uk

Put a piece of paper, cloth, leaf, insect (such as mosquito's leg, fly's eye, butterfly's wing), your hair or finger under an optical microscope, you will see amazing pictures which are not visible directly with naked eyes. A microscope is an instrument designed to magnify a small object so that it can be directly viewed by human's naked eyes. About 340 years ago, Robert Hooke observed honey-comb structures from a piece of cork tissue through the first optical microscope he invented, and called them "cells". Since then small objects like cells and tissues are routinely examined under optical microscopes in scientific laboratories, hospitals, schools, colleges, and even at homes by curious kids for having fun.

With a good microscope, one possibly will be able to view the red cells in blood. However, one will not be able to see the smaller structures inside cells, like proteins and DNA, no matter how good the microscope is, because conventional optical microscopes have limited resolution, which is not due to any manufacturing imperfections, but fundamentally restricted by the laws of physics. According to the diffraction theory of electromagnetic waves, the resolution of a microscope is basically determined by the wavelength of light used, which says the best resolution achievable is about half the wavelength of light. Optical microscopes, which operate with visible light with wavelengths ranging from about 400 nm to 700 nm, can only resolve objects with details of about a few hundreds of nanometers, a size about a hundredth of a human's hair. To see smaller structures like proteins, DNA and some viruses (like the HIV virus which has a size of about 100nm), one has to use shorter wavelengths, e.g. X-rays, or electrons. However, the application of x-ray or electron sources is restricted only to certain categories of objects. Furthermore, the methods are quite aggressive and could cause potential damage to living cells. Numerous efforts have been devoted in the scientific community to develop methods using visible light that can resolve objects with a resolution far beyond the diffraction limit.

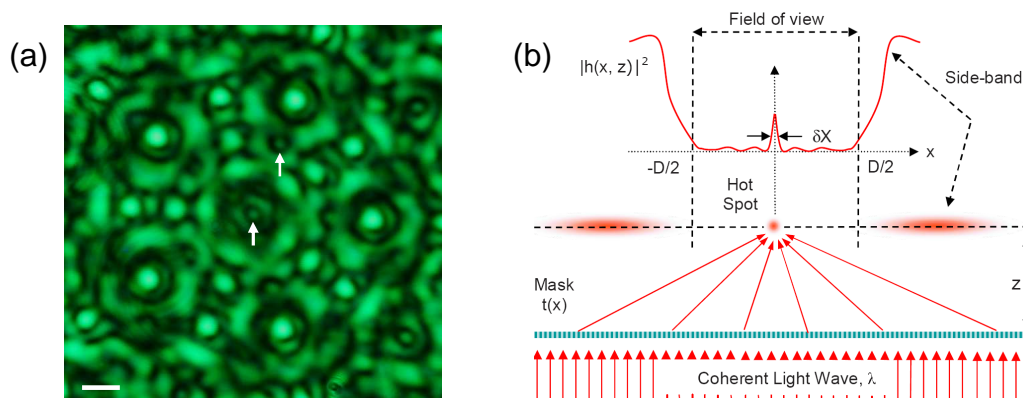


Fig.1 (a) Optical diffraction pattern containing subwavelength spots (pointed by arrows) was imaged with a conventional optical microscope. The wavelength is 500nm. Scale bar: 1 μ m. (b) Arbitrary field distribution with an arbitrarily small hot-spot δx , within a limited area $[-D/2, D/2]$, can be generated at any prescribed distance z by diffraction of a plane electromagnetic wave from a purposely designed mask, based on the principle of superoscillation.

Why is the resolution of a conventional microscope limited? Generally speaking, the field of a point object contains two components, one is the high spatial frequency component (larger than the wavevector of light) and the other is the low spatial frequency field component (lower than the wavevector of light). The high spatial frequency field is related to small details of an object, but decays exponentially when propagating in space and is therefore lost in the far field, therefore it is called *evanescent field*. Only the low frequency field component (propagating fields) exists in the far field, which forms a blurred imaging spot, no smaller than the so-called *diffraction limit*. Based on this understanding, many superresolution approaches are devoted to exploiting or recovering evanescent fields, such as the scanning near-field optical microscope (SNOM) and the superlens, therefore their



applications have a common restriction [1]: objects have to be put at immediate proximity to superlenses or near-field probes.

Recently we began to develop a different approach for superresolution, which does not depend on evanescent fields and therefore is capable of generating truly far-field superresolution imaging. Our approach is based on a phenomenon called *superoscillation* [2], which indicates that band-limited functions actually can oscillate arbitrarily faster than their highest Fourier frequency component. A sophisticated interference of propagating fields is able to generate field features smaller than the diffraction limit at distances beyond evanescent fields. We have experimentally observed such superoscillations in optics through light diffraction from a quasi-periodic nanohole array with SNOM [3] or even directly with a conventional optical microscope (Fig.1(a)) [4]. In fact, an arbitrary field distribution with any shape and size can be generated with propagating fields only. Such a field within a limited area can be physically realized through diffraction from a purposely designed mask when illuminated with a monochromatic wave (Fig.1(b)), which can be used for subwavelength imaging [5].

There are huge potential applications for the far-field NANOSCOPE. As objects can be placed some distance away from the imaging device, it is non-contact, non-invasive, fast speed, and most of all may image the internal structures of biological specimens, like cells and proteins. Applications in other areas may also be envisioned, like lithography, data storage and optical trapping.

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