Imaging with Light at Lengths Less than Lambda

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Optical imaging is limited by wave diffraction to a scale determined by the wavelength λ (lambda)—for visible light the shortest wavelength is around 400 nm so the use of visible light for imaging, patterning or manipulating nanometre-scale objects would seem to be a hopeless task. However, visible light sources are cheap and abundant, and many materials or systems we might want to image are not adversely affected by long exposure to visible light (e.g. biological systems), so there are some compelling reasons to challenge conventional diffraction limits for imaging.

One approach for sub-wavelength imaging is to simply study and understand diffraction limits more carefully. Abbe's classical diffraction limit states that the minimum resolvable separation between two closely spaced objects is ***half*** the wavelength used for imaging, which immediately makes sub-wavelength imaging possible with conventional microscopes. Abbe's limit also implies that the minimum resolvable *linewidth* (at half-pitch duty cycle) is a ***quarter*** of the wavelength, and by imaging in media with large refractive indices the *effective* wavelength can be reduced to even allow sub quarter-wavelength imaging.

A contemporary application for pushing optical imaging to these limits is semiconductor lithography, and this talk will begin by introducing the techniques that are employed and engineering challenges that must be overcome in order to print current-generation 32-nm scale features using light with a wavelength of 193 nm (lambda/6).

Resolution beyond these diffraction limits is also possible using near-field optics or nonlinear imaging processes. A number of these different techniques will be reviewed, including remarkable and practical techniques with acronyms such as STED, PALM and STORM that are pushing the resolution limits for visible-wavelength fluorescence microscopy towards the molecular scale.

In near-field imaging unlimited resolution is theoretically possible. We have explored this in the context of semiconductor lithography and have come to understand the important practical considerations that must be met in order to image at lengths less than lambda/10. We have even been able to project a near-field image through a silver 'superlens', to show that more is possible with near-field imaging than might first be assumed. Work in this field will be reviewed and our contributions highlighted, with hints given to some of the directions we see the research heading in the near future.