Selected probes for Scanning near-field optical microscopy (SNOM)

Sandra Eibenberger

14.5.2009

Outline

- Introduction into SNOM („Scanning near-field optical microscopy")
- Challenges
- Experiments:
  - Single molecule as a light source for SNOM
  - Single gold particle as a probe for SNOM

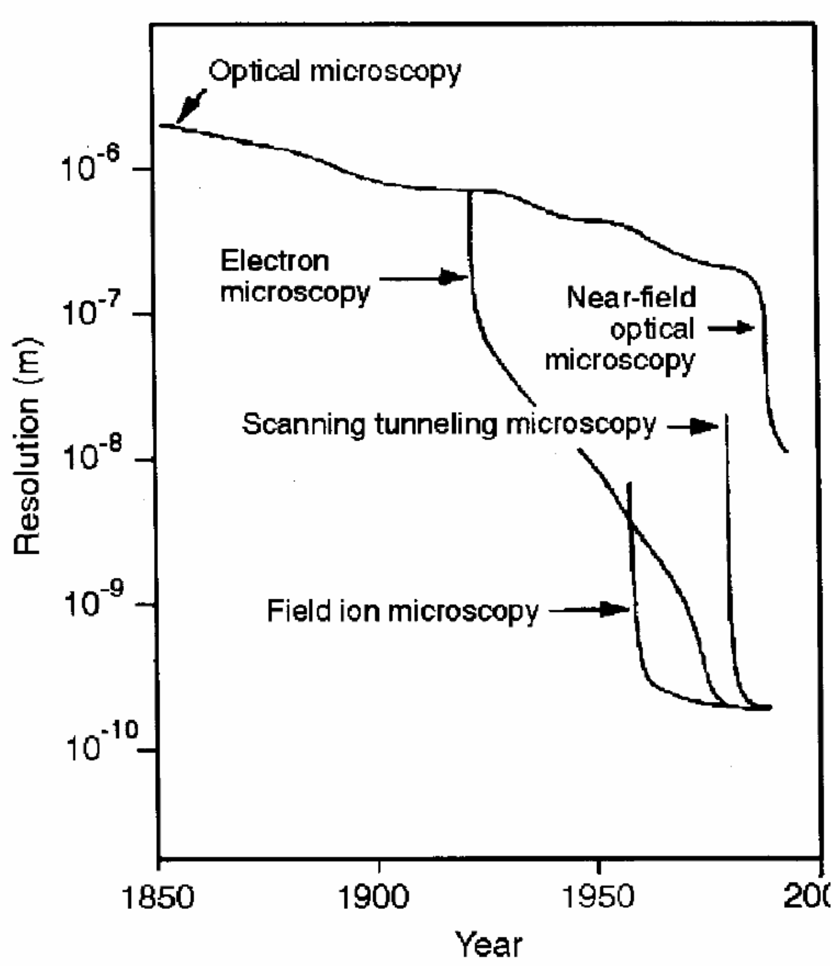
Measuring the near fields - SNOM

Classical diffraction limit:

Abbe: $$d = \frac{\lambda}{2n\sin\theta}$$

Resolve objects that are closer than d?

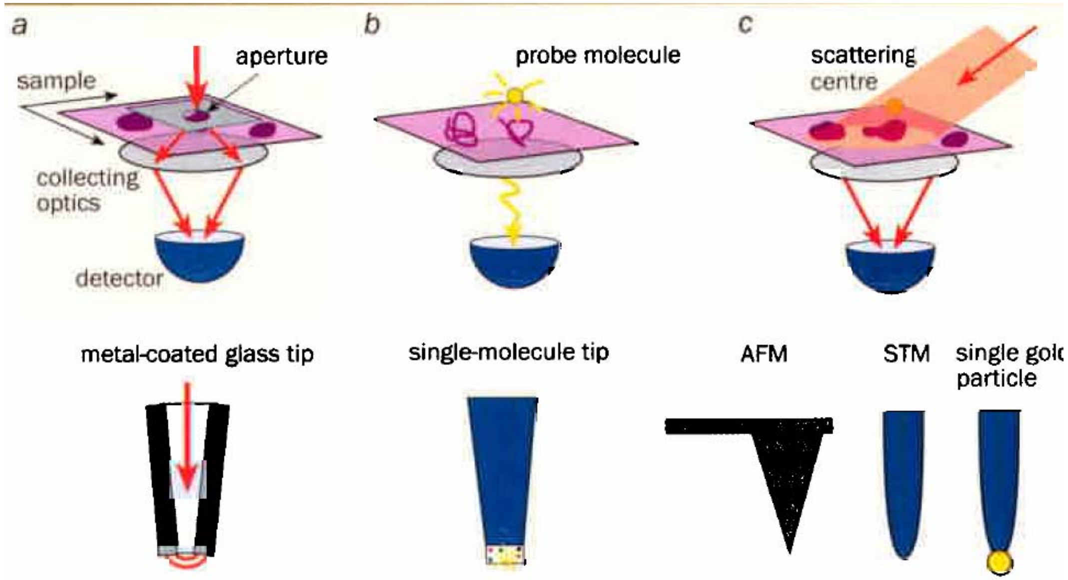
→Near fields: Evanescent waves contribute significantly to the field



Measuring the near fields - SNOM

- **1. Aperture SNOM**:
  The evanescent field at the end of a small aperture is locally scattered by an object. Detection of the scattered light is possible in the far-field.

2. Aperture-less SNOM:
A tiny probe of sub-wavelength dimension locally scatters the near-fields of an illuminated object. The scattered light is detected by a far-field detector.



Challenges of aperture SNOM

Crucial point: **Size** and **brightness** of **aperture**

Depends on quality of the probe **fabrication process**:
- Difficult to manufacture probes with apertures ~ 50 nm in a controlled way
- Aperture in a metal coated glass probe cannot be made arbitrarily small

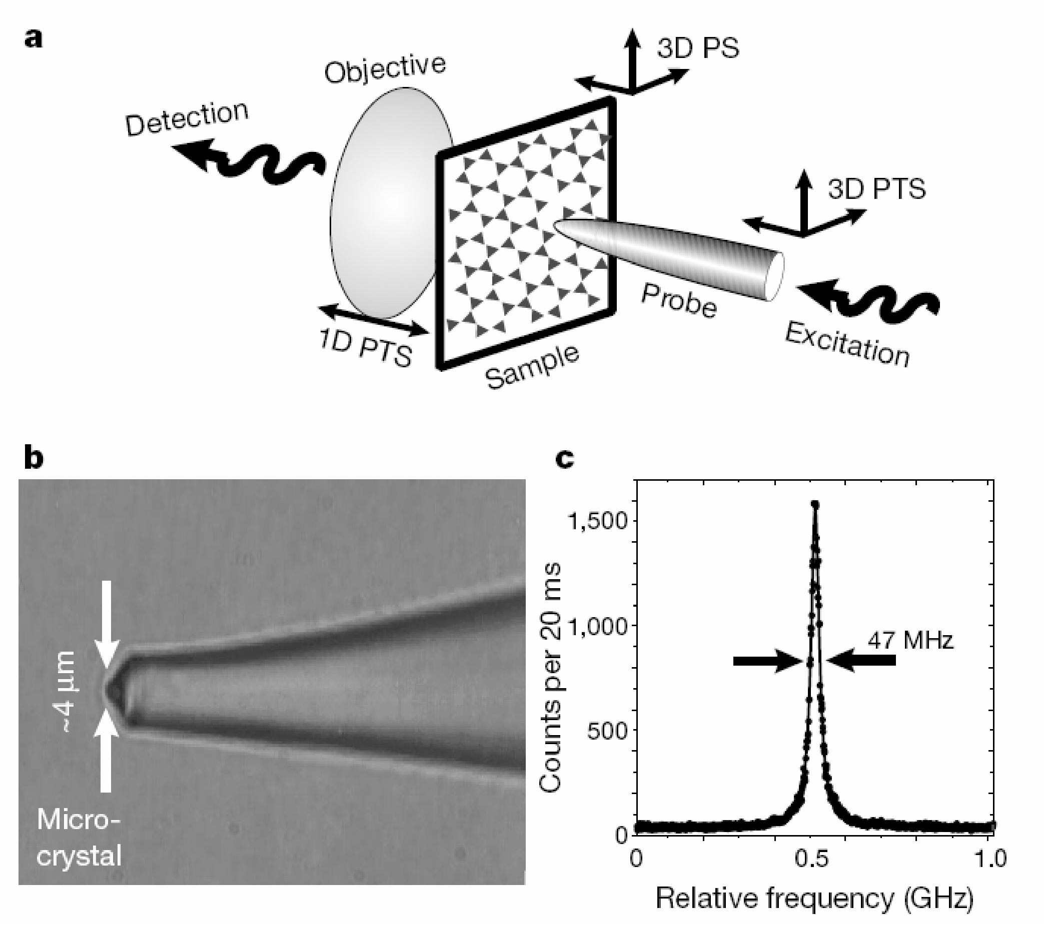
Fundamental limit for effective aperture size in the laboratory: **finite skin depth** (~7 nm for aluminium) of real metals

Single-molecule as a light source

Fundamental limit for aperture size → possible solution:

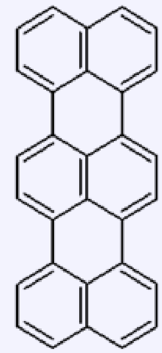
Tiny light source → **single fluorescent molecule**

- Scan single fluorescent molecule across a sample
- Collect scattered light as in conventional SNOM
- 1st proposed 1991 realized 1999 in Konstanz



Single-molecule as a light source – Experimental realization (Michaelis et al.)

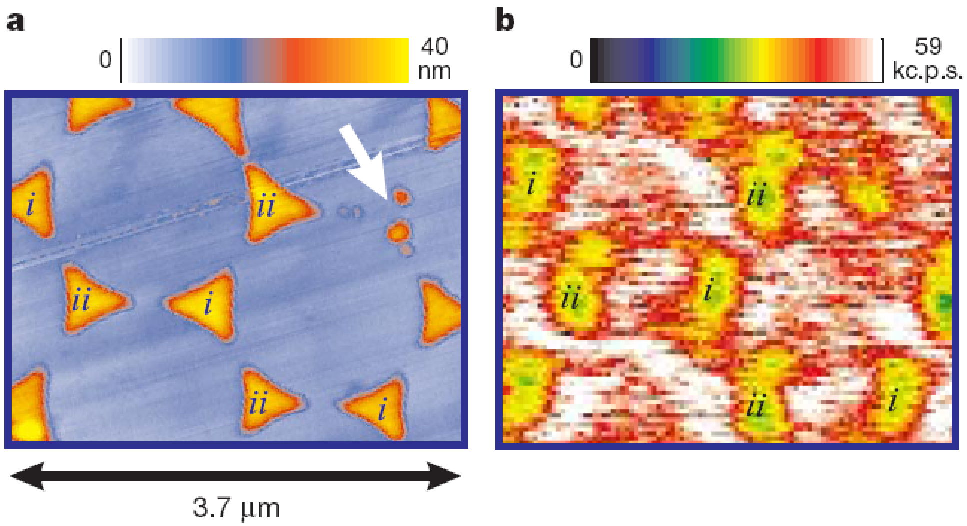
- At the end of fibre: micron-sized p-terphenyl crystal doped with terrylene molecules (concentration 10^{-7})
- Spatial doping concentration: collective excitation at room temperature at λ = 514 nm
- Choose microcrystal → glue to end of a single mode fibre → transfer to cryogenic setup
- Energy of ground and excited state of every molecule is modified by local environment
  → different transition frequencies
- Excite individual molecule by tuning the laser frequency
- Detect fluorescence at λ ✍ 630 nm by an avalanche photodiode
- Shear force signal used to regulate separation between sample and molecule



Terrylen

Single-molecule as a light source – Experimental realization (Michaelis et al.)

- Laser tuned into resonance with one molecule
- Probe moved nearer the sample until shear force signal sets in
- Fixed axial position → scan
- Signal drops each time a metallic island blocks the transmission



Sample: 25 nm high, triangular aluminium islands

Arranged in hexagonal lattice with period 1,7 µm on a cover slide

Dependency on probe-sample distance

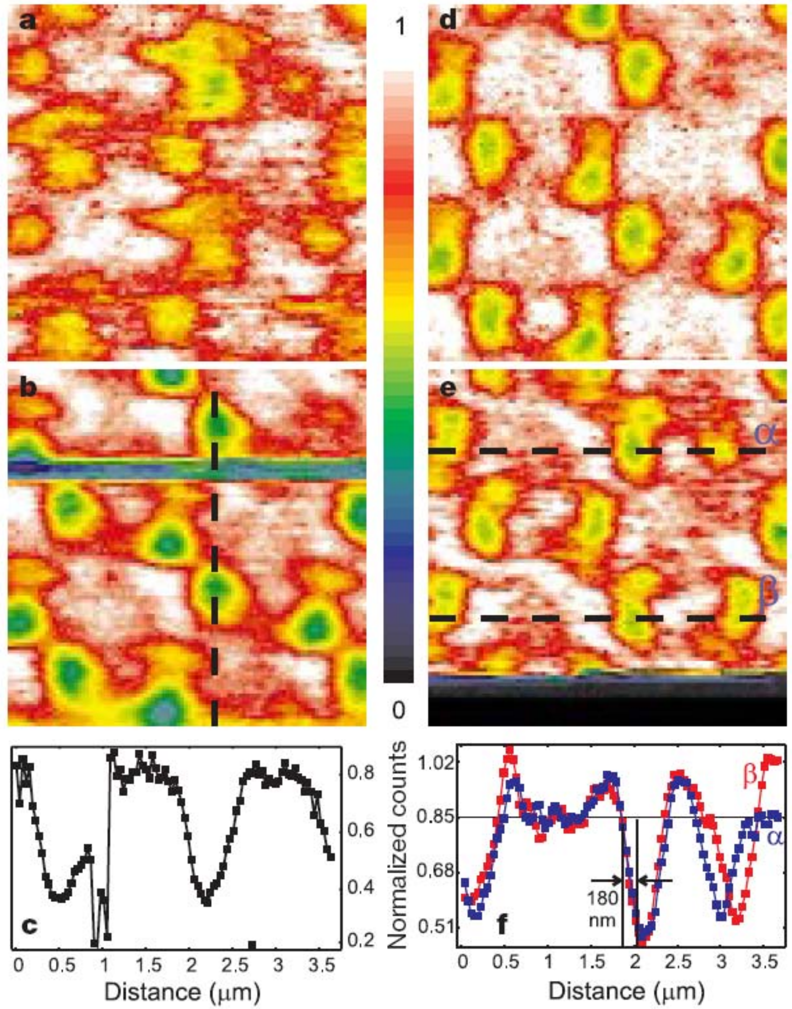
a) 350 nm
b) 80 nm
d) 50 nm
e) 20 nm

The smaller the distance the better the image

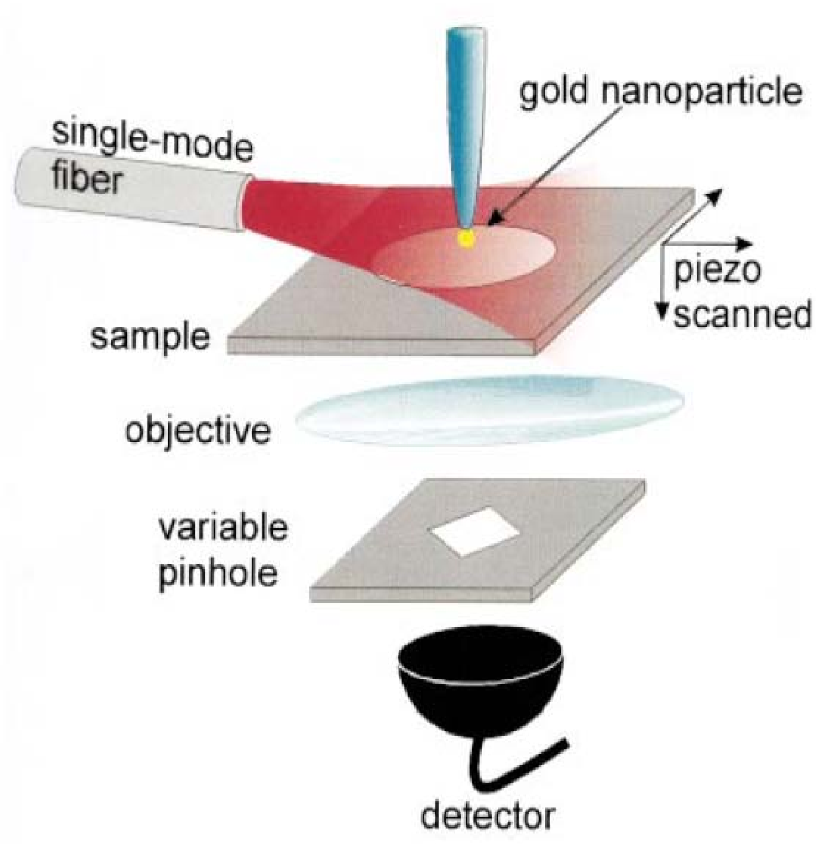
Resolution: ~ 180 nm (less than λ/3)

Not molecular resolution: matter of luck to excite molecule that sits exactly on outer edge of the crystal to fully exploit near fields

→ Experiments with nanocrystals (~ 200 nm wide): light from any molecule has the chance to reach the near field



Single gold particle as a probe



Aperture-less SNOM:
based on scattering of non-propagating fields when a tiny object is illuminated

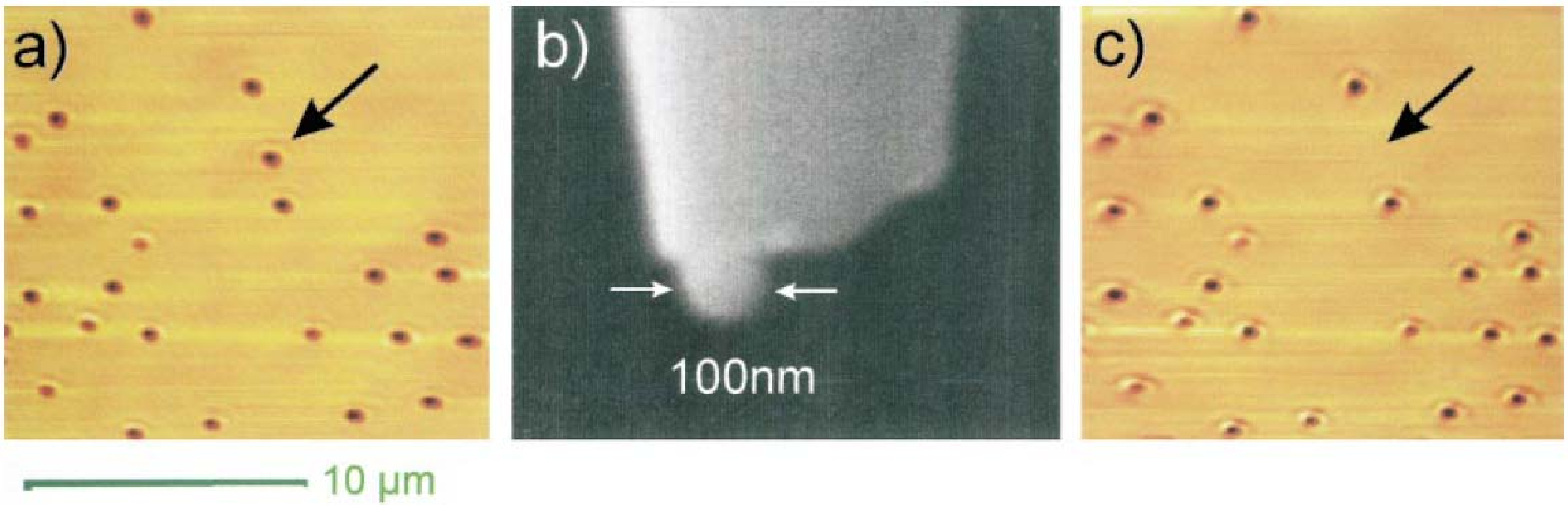
Conventional: AFM tip or sharp metallic tip

→ Far field illumination over large area → stray scattering from sample and/or tip shaft
→ bad signal to noise ratio

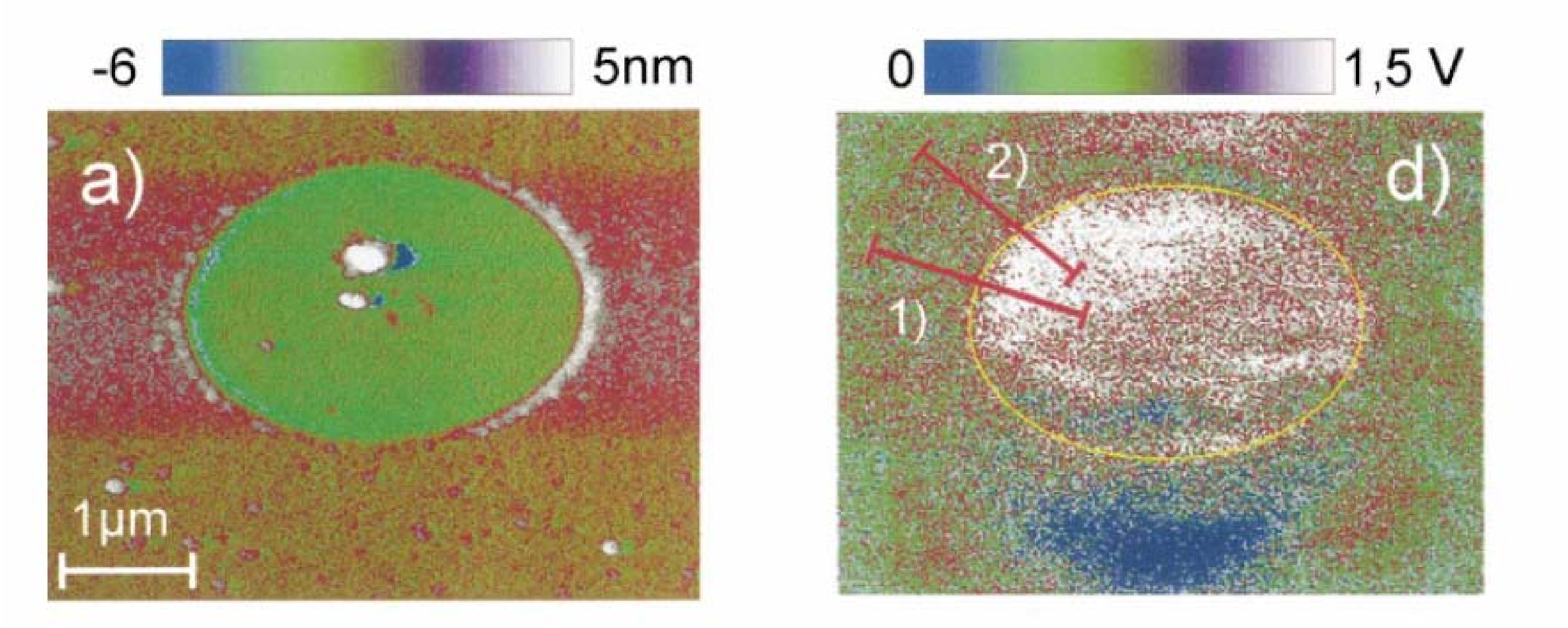
Approach of Kalkbrenner et al.: single gold nanoparticle

Single gold particle as a probe

- Well-defined nano-scatterer
- Control the optical response of the probe to a high degree
- Collective oscillations of the electrons in the nanosphere
- Resonance at particular wavelengths
  → possible to distinguish the contribution from the ones of the shaft or the sample



Single gold particle as a probe - Results



- Sample: Thin Aluminium-film containing isolated holes of 3 µm diameter on a glass substrate
  a) Topography signal
- Edge sharpness: ~100-200 nm

Thank you!

References:

- Michaelis, J., Hettich, C., Mlynek, J. & Sandoghdar, V. Optical microscopy using a single-molecule light source. Nature **405**, 325-328 (2000)
- Kalkbrenner, T., Ramstein, M., Mlynek, J. & Sandoghdar, V. A single gold particle as a probe for apertureless scanning near-field optical microscopy. J. Microsc. **202**, 72 (2001)
- Sandoghdar, V. Beating the diffraction limit. Physics World **14**, 29-33 (2001)