Near-field optical microscope using a silicon-nitride probe

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Operation of an alternative near-field optical microscope is presented. The microscope uses a microfabricated silicon-nitride probe with integrated cantilever, as originally developed for force microscopy. The cantilever allows routine close contact near-field imaging on arbitrary surfaces without tip destruction. The effect of adhesion forces on the coupling to the evanescent wave has been observed. Images with a lateral resolution of about 50 nm are presented and compared with atomic force images. A specific sample area can be selected using an integrated conventional light microscope.

Scanning near-field optical microscopy based on localized frustrated total internal reflection (FTR) has been demonstrated by some groups over the last years.[1–3] In these microscopes an optical fiber sharpened to 50–200 nm is used as a dielectric probe to convert an evanescent wave into a propagating wave. The technique is often referred to as photon scanning tunneling microscopy (PSTM). A lateral resolution of 10–50 nm is claimed, generally based on edge steepness. Yet application of the microscope is still limited compared to other scanning probe techniques as scanning tunneling and atomic force microscopy (AFM). In fact PSTM suffers from some fundamental drawbacks.[4] First, the presence of a sample causes both modification of the evanescent wave and generation of propagating waves due to scattering. Hence images generally contain both localized near field and long range far-field effects which are hard to discriminate. Second, a single tip touch to the sample is generally fatal. Third, the optical feedback mechanism based on coupling to an evanescent wave only works on samples with limited structural features at a working distance of typically 100 nm. Yet for high resolution near-field optical imaging of arbitrary surfaces it is essential to have a distance regulation mechanism which enables close contact scanning at a distance below 20 nm independent of the optical properties of the sample. Recently Prater[5] and Tortonese[6] demonstrated near-field imaging with force feedback using a microfabricated Si membrane with an aperture, however optical resolution was still limited to 0.25 μm. A promising alternative based on lateral force feedback in a dynamic detection scheme has been reported by Betzig *et al.*,[7] using coated adiabatically tapered fibers with apertures down to 20 nm,[8] and by Toledo-Crow *et al.*,[9] using micropipettes. However application of these probes is limited to samples with gentle surface roughness as the outer diameter at the apex is generally larger than 0.25 μm.

We demonstrate an alternative to the PSTM taking advantage of the microfabricated SiN probes commonly used in AFM. The SiN probe is a high index ($n=2.0$) optically transparent structure with 20–50 nm apex integrated with a cantilever, which can be operated in close contact simultaneously as an optical and a force probe.[10] In this letter we present first results of near-field optical imaging using a SiN force probe, applied to test structures, optical thin films and chromosomes.

The experimental setup is shown in Fig. 1. An evanescent wave is generated on a glass substrate by total internal reflection of a 5 mW HeNe laser beam focused to 200 μm. Samples are prepared on a glass support which is placed on the substrate with an index matching liquid. The optical probe is a microfabricated SiN cantilever (0.06 N/m) with integrated pyramidal tip (20–50 nm apex, Park Scientific Instruments). The cantilever is placed at a 15° angle to the substrate. A long working distance objective (40X, 0.5NA, 10 mm) collects the light generated by FTR at the SiN apex. A pinhole in the imaging plane is adjusted such that only light from the SiN apex passes onto a photomultiplier.

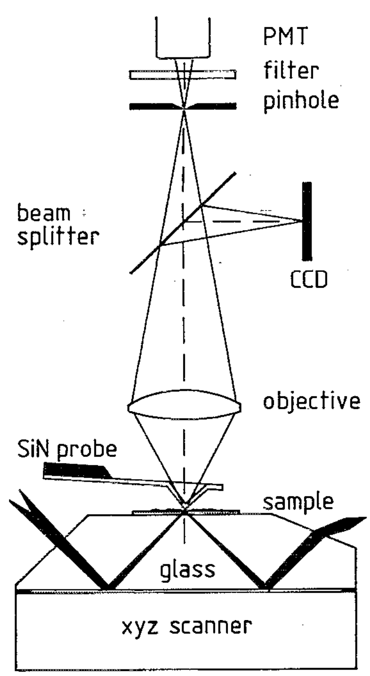

FIG. 1. Set-up of the near-field optical microscope with SiN probe.

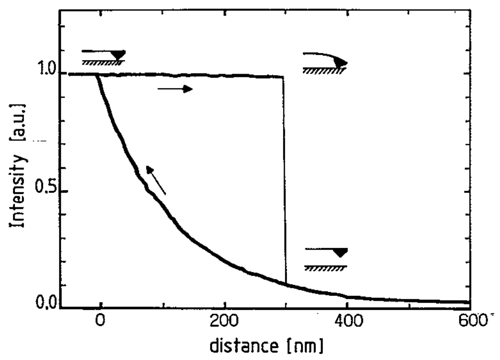

FIG. 2. Optical signal as a function of tip-substrate distance on approaching and retracting the SiN probe.

Images are obtained by scanning the sample in contact with the probe. Part of the light path is split towards a CCD camera which allows simultaneous viewing of tip and sample.

When approaching the probe to the substrate an exponential increase of optical signal is observed, as displayed in Fig. 2, corresponding to the expected coupling to the exponentially decaying evanescent wave,[3] until the tip jumps into contact. On retracting the probe contact is maintained due to the adhesion force of the waterfilm on the surface, resulting in a constant optical signal of the order of 0.1 nW. The cantilever typically bends over 300 nm (at 65% relative humidity), corresponding to 20 nN adhesion force, until it jumps out of contact, resulting in an abrupt decrease of the optical signal. The curve displayed in Fig. 2 is the optical analog to the force-distance curve common in force microscopy.[11]

Figure 3(a) displays a near-field optical image of a 1 μm period grating, consisting of a microscope cover glass with SiN lines, 200 nm high and 500 nm wide. For comparison the topography of the same sample is displayed in Fig. 3(b) in an AFM image, scanned with a similar SiN probe in a constant force mode.[10,12] The glass trenches between the SiN lines are narrowed to a width of 175 nm due to a tip convolution effect. In the optical image the lower glass trenches appear light against the SiN top layer because the coupling of the evanescent wave from the low index glass to the high index SiN probe is more efficient than from the SiN lines to the probe. Also partial reflection

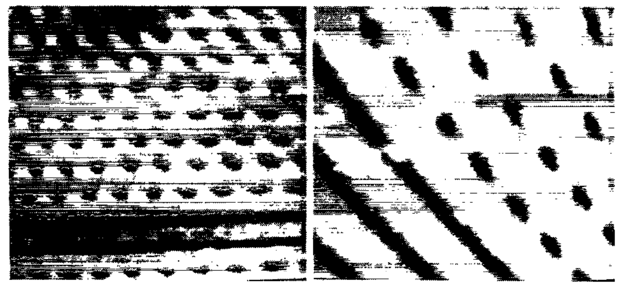

FIG. 4. (a) 8×8 μm optical and (b) 4.5×4.5 μm force image of a compact disk test structure.

at the glass SiN transition within the sample might influence the observed contrast. Figures 4(a) and 4(b) show an optical and a force image, respectively, of a polycarbonate compact disk test structures with indented tracks of pits and lines. The track spacing is 800 nm. The pits are 175 nm wide and 50 nm deep. Similarities between the optical and force image indicate that the optical contrast is mainly determined by surface topography. Figures 5(a) and 5(b) show an optical and a force scan, respectively, over an indium-tin-oxide film (Baltracon). Crystallites of 30–200 nm in size are clearly resolved in the force image. In the optical image similar structures are resolved, however, the grains appear dark against the background due to their higher refractive index and limited transmissivity. The lateral resolution in the optical image is about 50 nm, while the AFM resolution is 10–40 nm, limited by tip convolution effects. Integration of the high NA objective is essential for location of a sample area of specific interest. As an example the first near-field optical image of a metaphase Chinese hamster lung chromosome is shown in Fig. 6 as it was also recently investigated by AFM.[12] The chromatides reduce the coupling to the evanescent wave causing the chromosome to appear dark among its surroundings. To the right of the chromosome is a rather intense radiative contribution caused by scattering at the chromosome of the laser beam propagating from left to right.

In conclusion, a microscope has been presented which allows routine detection of localized FTR in close contact scanning on arbitrary surfaces. Use of SiN probes eliminates fundamental practical problems in PSTM operation. The method can be readily incorporated in a conventional

FIG. 3. (a) Near-field optical image of a 1 μm period SiN grating and (b) AFM image of the same sample in constant force mode. Both 6.5 ×6.5 μm scan area.

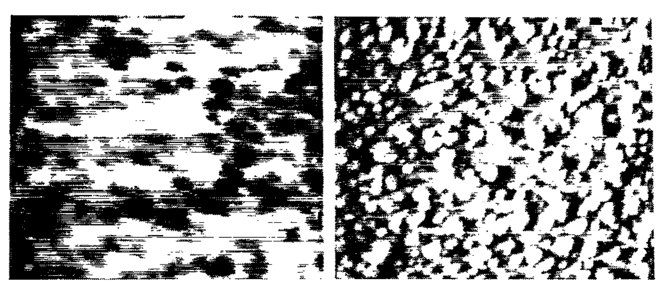

FIG. 5. (a) 3.5×3.5 μm optical and (b) 2.6×2.6 μm force image of an indium-tin-oxide film.

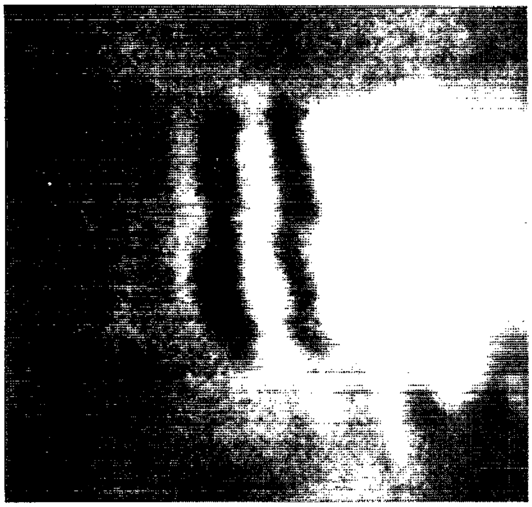

FIG. 6. Near-field optical image of a Chinese hamster lung metaphase chromosome, 15×15 μm scan area.

force microscope. A lateral resolution down to 50 nm is observed. The optical contrast is determined by surface topography, refractive index, and transmissivity variations, however full understanding of the contrast mechanism and the effect of far-field contribution requires further analysis.

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