Super-Resolution Imaging on Microfluidic Super-Resolution Near-Field Structure*

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We present a new concept of the microfluidic super-resolution near-field structure (MSRENS) based on a microfluidic structure and a super-resolution near-field structure. The near-field distance control, "nano-probe" and scanning can be realized simultaneously using the MSRENS, which is similar to a near-field scanning optical microscope. The design and simulation results are presented. Numerical simulation has demonstrated that the MSRENS with spatial resolution beyond the diffraction limit could be applicable in chemistry, biologics, and many other fields.

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Various microfluidic components have been successfully fabricated and microfluidic devices have been developed for advanced applications in biotechnology, analytical and clinical chemistry.[1−3] Microfluidic structures are operated on liquids with high transverse resolution, but without high longitudinal resolution.

Near-field scanning optical microscopes (NSOMs) with high spatial resolution beyond the diffraction limit are widely applied in the research fields such as high-density data storage, photolithography, and biological observation. On the other hand, NSOMs have some problems: a metal coated optical fibre tip is very fragile, and the fibre tip must be carefully controlled on the detected sample surface in a distance of about a few tens of nanometers, and the scanning speed is very slow. In order to overcome these problems and simultaneously to achieve a high spatial resolution beyond the diffraction limit, Tominaga *et al.* first proposed the super-resolution near-field structure (super-RENS), which was developed as a new technique for ultra-high-density optical data storage and nanolithography.[4−6] This structure has the best advantage that neither protruding fibre probe nor near-field distance control is required, because the nano-probe can be formed in the Sb- or AgO_x-mask layer under laser beam illumination[4,5,7−9] and the near-field distance is fixed by a sputtered spacing layer.

In this Letter, we present a new concept of microfluidic super-resolution near-field structure (MSRENS) based on the microfluidic structure and the super-resolution near-field structure to image the microfluid. The near-field distance control, nano-probe and scanning can be realized simultaneously using the MSRENS. The basic idea is that biological and other liquids flow in micro channel of the MSRENS, the flowing of the fluid in micro channel provides scanning of NSOM and the scanning speed is equal to the flowing speed; the scanning area can be much longer. The nano-probe acting as a NSOM fibre tip must be formed. For example, a nano-probe can be formed in the mask layer under laser beam illumination similarly to super-RENS,[4,5,7−9] which works as a dynamic near-field optical probe, and a fixed nano-probe can also be fabricated in the near-field mask layer using electron beam nanolithography.[10] Furthermore, the fluid object and the mask layer film are separated by a transparent solid film with a thickness of about a few tens of nanometers, which can be deposited by sputtering and other techniques with a unique film thickness over a wide area, this solid film works as the near-field distance controller.

When objects move over the nano-probe in the vicinity of the near field, the nano-probe can radiate the fine signal of samples to far field. This far-field radiation is collected by a microscope objective with large numerical aperture and is sent into a photomultiplier. Thus, this MSRENS can work with various models similarly to NSOM and can achieve a high spatial resolution beyond the diffraction limit.

We numerically simulate the MSRENS used to detect a moving object. Figure 1 shows the schematic diagram of the simulation model. We choose the Sb- or AgO_x-mask layer that is the same as the super-RENS proposed by Tominaga.[4,11] The refractive indexes of the microfluid and the moving object are 1.33 and 1.39 respectively. The wavelength of the incident laser beam is 633 nm. The sizes of the nano-probe and the moving object both are 200 nm. Other parameters

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of the simulated model are taken from Ref. [12]. In order to obtain the contrast of the readout signals, we define the contrast to be

$$\Delta R/R = (R_{\max} - R_{\min})/((R_{\max} + R_{\min})/2), \quad (1)$$

where R is the sum of the reflected Poynting vectors.

Figures 2(a) and 2(b) show the Poynting vector distribution in the nano-probe formed in the Sb- or AgO_x-mask layer. It is obvious that the structure with the Sb- or AgO_x-mask layer functions as the NSOM with the aperture or metallic tip (nano-scattering centre), respectively. When the mask layer is AgO_x, there appear two noteworthy stronger enhanced sharp peaks at both edges of the scattering centre (silver nanoparticle). Because the AgO_x is decomposed into silver nanoparticles (cluster) in the hot region under the focused Gauss beam,[8] the enhanced surface plasmon local field arises around the silver particles. This distribution of enhanced local field functions as two-tip scanning.

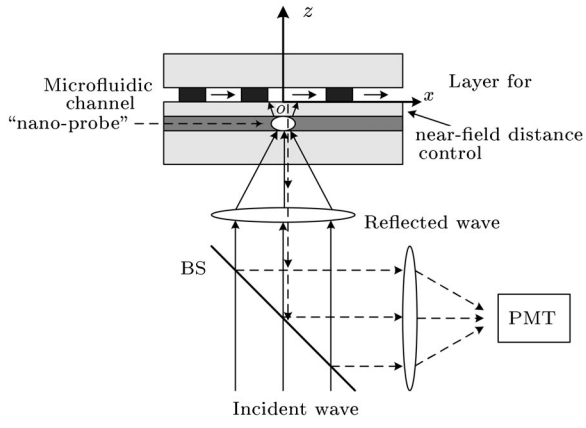


Fig. 1. Schematic diagram of the MSRENS system.

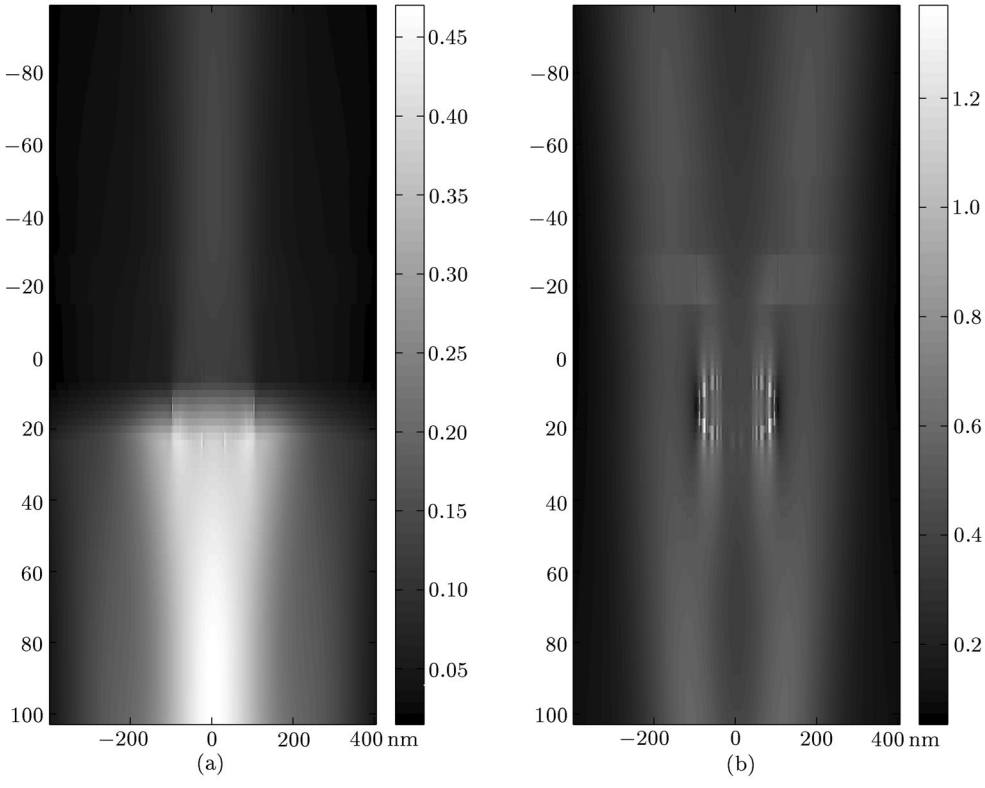


Fig. 2. The near-field electric field intensity distribution in the (a) Sb or (b) AgO_x layer.

The readout signals $\Delta R/R$ of both the different-mask-layer structures are shown in Fig. 3 (the $\Delta R/R$ curves is symmetrical to $x = 0$, the curves from -600 nm to zero is not shown). The peak can appear when the moving object just passes over the nano-aperture formed in the Sb-mask layer. According to Eq. (1), we can obtain $\Delta R/R = 0.14\%$. When the mask layer is AgO_x, there appears to be two peaks in the curves, because the distribution of enhanced local field at both the edges of the silver nanoparticle functions as the two-tip scanning, and $\Delta R/R = 1.45\%$ is much larger than that of the Sb-mask layer structure, due to field enhancement of surface plasmon. Figure 4 shows the readout signal $\Delta R/R$ as different sizes of the nano-scattering centre formed in the AgO_x-mask layer structure, the corresponding scattering centre size are $D = 100$ nm and 200 nm, respectively. From Figs. 3 and 4, it is clearly shown that the full width at half

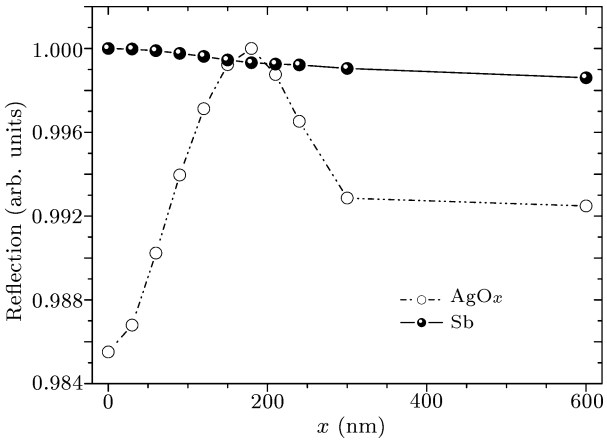


Fig. 3. Readout signal $\Delta R/R$ versus the object position x.

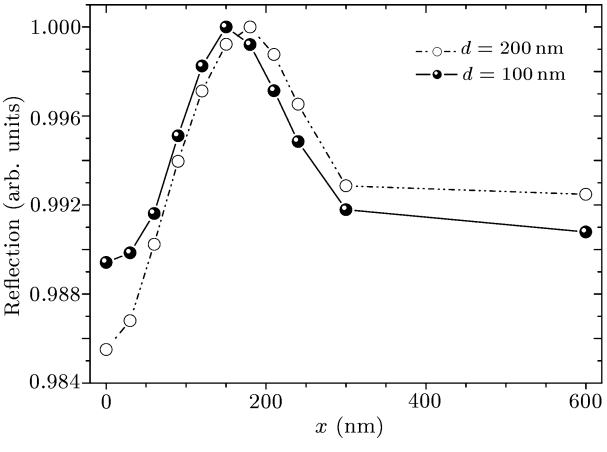


Fig. 4. Readout signal $\Delta R/R$ at different sizes of the scattering centre of the AgO$_x$-mask layer structure.

maximum (FWHM) of the $\Delta R/R$ curve is 200 nm, which is equal to the size of the moving object. Anyway, the FWHM of the $\Delta R/R$ curve represents the size of moving object. In other words, when the MSRENS is used to image microfluid or other moving micro-object, its FWHM is the size of the detected object if the $\Delta R/R$ curve can be obtained.

In conclusion, we have presented a new concept of the MSRENS. The near-field distance control, near-field probe and scanning can be realized simultaneously using this structure. The design and simulated readout signals of the MSRENS to image microfluid have been carried out. The calculations and correlative successful experiments[4,5,10] have demonstrated that the MSRENS with ultrahigh spatial optical resolution is applicable in chemistry, biologics, and many other fields. This structure has been fabricated and spatial resolution experiments are in progress.

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