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Sub-Diffraction Optical Probe Design Considerations

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Scanning Near-field Optical Microscopy (SNOM) employs many different forms of optical probes to achieve sub-diffraction limited imaging. The first commonly used probes utilized optical fibers pulled or etched to a small end diameter. This technique has successfully demonstrated better than 100 nm spatial optical resolution. These original near-field probes utilized a coating of Aluminum on the sidewalls to achieve field confinement (with coating while rotating), making a decent probe that achieved below 50 nm was a needle in a haystack situation.

The fabrication process had problems with; irreproducible coatings, leading to light leakage or coatings blocking the light, insensitive scanning surface interaction mechanisms, or taper issues leading to low throughput. To overcome these issues a probe design, which involved illumination of sharp metals with optimal polarization was developed to achieve higher topography and optical spatial resolution. This technique has been termed Tip Enhanced Near-field Scanning Optical Microscopy (TENOM). TENOM also allows for the use of multi-photon excitation laser sources, aiding in the suppression of far-field background signal. Fabrication of these probes requires the use of nano-manipulation systems to achieve the correct shape. Systems such as dual-beam focused ion beams (FIB) were making their way into the university research environment at the right time.

Before the FIB capabilities, the hit and miss nature of probe fabrication slowed progress. In addition, without the use of a field emission scanning electron microscope (FESEM) to inspect the probes there was no reliable method for verifying light confinement. In addition to the TENOM probes relying on the FIB, fiber probes have benefitted greatly from these fabrication systems. With proper milling (FIB) and inspection (FESEM), fiber probes can be very reproducible.

Although the TENOM probes demonstrate higher optical and topographical resolution than fiber probes, in general the fiber probes with proper modification can achieve similar results. Utilizing numerical modeling for electromagnetic interactions on the nanoscale, we have modeled many promising designs that could be very useful in near-field applications. We utilize Fresnel equations and finite difference time domain (FDTD) to optimize probe designs. With the help of the dual beam FIB, we have been able to create these probes.

TENOM probes have issues as well, which prevent their use by many researchers seeking to use a sub diffraction imaging process. The biggest problem is what geometry to make. A geometry that generates a large localized field enhancement is ideal. Larger enhancement factors, increase the signal to noise ratio, effectively suppressing the far-field background contribution in the image. In terms of fluorescence imaging quenching can be an added a problem for fluorescence systems, which have the chromophores within 10 nm of the probe, tip. There are some fixes for this issue, which involve scanning at a higher distance over the sample, or SiO_2 coatings on the end probe. For Raman imaging this quenching issue is not a problem but a positive feature of a TENOM probe. These features could be integrated into the design. Ultimately the best geometries should have a surface plasmon resonance with the wavelength of excitation light used. This talk will present our latest results [3,4,5] and important considerations for problems encountered in the making and design of these probes.

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