
**Novel Split-Tip Proximal Probe for Fabrication of Nanometer-Textured, In-Plane Oriented Polymer Films**

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Novel fabrication schemes are required to deposit nanoscale materials that contain molecules oriented in the plane of the surface. Such a symmetry breaking allows devices to be fabricated in this plane, as has proven successful in semiconductor devices. We discuss here the fabrication of a novel split-tip optical nanoprobe that can be used to both orient the molecules with a strong, local electric field, and deposit the molecules with ultraviolet light injected through the probe into the region of aligned molecules. The production of such a split-tip probe is significantly different than that of the related near-field scanning optical microscope (NSOM) probe since the stresses in the metal layer must be held by the metal film – silica interface rather than within the film as it circles the silica. Mounting of the probe to insure reliable electrical contacts is also described.

Keywords nanoscale deposition, conducting polymers, NSOM, nanoscale characterization

**Introduction**

Many complex materials and polymer or other molecular-based electronic devices depend upon the orientation of the components for their properties. This requirement places severe constraints on deposition techniques when lateral resolution on the nanometer length scale is required. We describe the fabrication of a scanning probe that can be used [i] to deposit polymer molecules that are oriented in the plane of the surface. This orientation is complementary to self-assembled monolayers, SAMs, for which the orientation is perpendicular to the surface, and obviates the need for deposition of an electrode on top of the SAM polymer molecules. The latter process is difficult, and often results in damage or destruction of the SAM due to the energy carried by the deposited species [ii, iii]. The probe enables new device structures, since it can reverse the orientation of deposited, non-symmetric molecules within nanometers. The result will be a potential barrier at the interface, which can be gated to provide device operation.

We present here the fabrication and electric connection of the central tool to enable this technique – the split-tip probe. The fabrication process is not obvious. We show here that methods developed for fabrication of near-field scanning optical microscope (NSOM) probes do not work well for fabrication of split-tips. The primary reason for failure is film stress and shorting problems. We model and show how these methods can be modified to successfully produce split tips. The electrical connection to the probes is also difficult,
due to the combined requirements of multiple connectivity without shorting on a 125 micron diameter fiber, while simultaneously mounting the fiber for successful lateral force microscopy so that the split tip can operate on a scanning proximal probe microscope system.

The split-tip probe, which is mounted onto a standard scanning proximal probe microscope, consists of two electrically isolated and independently contacted metal electrodes deposited on opposite sides of a tapered optical fiber, similar to those used for near-field scanning optical microscopy (NSOM). An electron microscope image of one of these split-tip probes is shown in Fig. 1. We use Al or Au for these tips. The NSOM system has the required optical hardware for coupling laser light into the region between the split-tip electrodes, which is exactly where it is needed for initiating the deposition to the surface. The probe not only guides the deposition, but can characterize the quality of the resulting material by (1) measurement of topography by the NSOM-like scanning probe, or (2) measuring orientation with polarization-dependent NSOM imaging with the probe that is also used for deposition.

**Design Requirements**

Before we describe the fabrication of the probe, we briefly describe the deposition scheme that it will be used for and some of the other criteria that impact the design of the probe. A schematic of the probe tip near the sample as molecules are being deposited with a fixed orientation to the sample surface is shown in Fig. 2. In this cut-away view, the electrodes are on the left and right sides of the tip. The electric field is localized in the region of the split, and is highest where the split is narrow – near the tip apex. Molecules that are in solution will be oriented where the field is high, but not elsewhere. When the tip moves to a new location, it aligns the molecules, then initiates the deposition to the sample with a pulse of ultraviolet light. The tip then moves to a new location, orients the molecules as they should be in the new location, and links them to the surface. It is important that molecules not under the probe tip do not attach to the surface, since they are not oriented. The schemes for insuring this are below. The molecules are shown in solution. This is not necessary. They could also

**Figure 1.** The split-tip probe. The electrodes are on the left and right sides, and the aperture is at the bottom.

**Figure 2.** A schematic of the probe illustrates the major features.
be deposited ‘dry’ onto the surface, those in the regions of interest be rotated by the field and linked to the surface, then the remainder washed off. Another alternative is to load the tip with molecules as in the ‘dip-pen’ lithography scheme, [iv] oriented and attached as in liquid, then another molecule chosen for a different position. All of these schemes have the same requirements for the probe.

The requirements for the tip are that two electrodes must be electrically isolated from each other, that ultraviolet light must be able to propagate through the probe to the region between the electrodes, that deposition must not occur on the probe itself, that the probe must be compatible with a microscope system, that the probe must not be ‘shorted’ by the solution or the molecules that are in the solution, that the probe be usable in a probe-surface distance regulation scheme and that the probe have a reasonable lifetime.

**Probe Fabrication**

Our 'split-tip' probe resembles an NSOM probe, and it is fabricated using a process similar to that used for our NSOM tips, but with a few significant differences that make the process work. We use either a Sutter Instruments puller, modified to work better with fibers, [v, vi, vii, viii] or chemical etching [ix] to taper the end of an optical fiber. We need to pull the fibers when we want a large separation of the electrodes, since the fiber gets a flat face as it cleaves in the fiber pulling apparatus, as can be seen in Fig. 3. This shape contrasts with the sharp point at the tip of properly-etched fibers. Thus, if the electrodes are to be brought in close proximity to the surface, they need to be close together with etched fibers, but may be further apart when pulled fibers are used. Etched fibers are more reproducible to fabricate in large quantities, and have a higher optical throughput. We initially used only pulled fiber probes for the fabrication of split-tip probes, since we were concerned that the electrodes might short near the tip, but we now use both types without shorting problems.

![Figure 3. SEM image of a larger-aperture tapered fiber fabricated by the heat-and-pull method. Note the flat cleaved end that is formed when this fabrication scheme is used, as opposed to the sharp point of etched fibers.](image-url)
Once the fibers are shaped, metal is coated on one side, then the fiber is rotated 180°, and the other electrode is deposited. This forms a split metal structure with the two metal sides electrically isolated. The metal coating must be thin so that the two sides do not short together. Our probe-holding fixture, shown in Figure 4, in the deposition chamber allows an accurate flipping of the probes in vacuum. The probes are mounted on holders that keep the probes straight and separated by a sufficient distance that they do not shadow each other during evaporation. Between 8 and 10 probes are held in each unit. Two units can be used at once in the evaporator system, facing each other. The probe holder is mounted on a large gear, and the fiber tails run through a series of holders, also mounted on the gear, in the direction so that they do not unravel during the rotation of the gear. The gear is turned by a smaller gear attached to a small electric motor. We have found that the motors work reliably in vacuum when they are driven by a voltage lower than their maximum rating, which also has the advantage that they spin more slowly. Although it is commonly taught that the back-voltage generated by the motor limits the current and that lower voltages result in motor over-current failure, we have found that the current is limited primarily by the resistance of the wires, when these small motors are under load. We have found that motor failure is usually the result of shorting from metal deposition or an increase in friction in the mechanism, often due to effects of metal deposition. The two gears provide a reduction of the motor rotation by a factor of ___. Copper braiding attaches the axle of the larger gear shaft to a liquid nitrogen cold trap mounted directly over the rotation units. In this way, the fibers can be cooled by radiation (with approximately \( \pi \) steradians of solid angle towards the cold trap) or by conduction through the Cu braids, shaft, gear, holder, and fiber shanks. The evaporation chamber allows three different source materials can be used during one pump-down. We use Al or Au. Following the initial deposition, a thicker coating of gold is applied to the contact regions on the shank of the tip. A small shutter, driven by an in-vacuum electric
motor is used to shield just the probe tips from the evaporation source, so that the shanks are coated with metal. A close-up view of the split-tip probe can be seen in Fig. 1, and a view at lower magnification is given in Fig. 5.

Figure 6. A split-tip probe fabricated by the same method that reliably produces good NSOM probes. The split line can be observed slightly to the left of the probe center, from this viewpoint. Peeling of the metal layer is complete near the tip and buckling is evident elsewhere. The end of the tip was broken, presumably as the metal left. (a)-(c) are increasing magnification, at the scale in the image.
A significant challenge in the fabrication process is insuring a well-defined split and a continuous coating of metal down to the aperture of the probe. The reason why this is much more difficult than for NSOM tips is that the metal forms a continuous ring around the diameter of the NSOM probe. If there is stress in the metal layer, the film itself will hold the stress. When the metal is thermally evaporated, the stress is typically tensile [ref]. This means that the metal will try to pull itself apart from the probe. If the metal is continuous, it will pull on itself, and usually remain stable. In the split tip, the metal is not continuous, so the stress must be held by the interface between the film and the underlying silica. Far from the tip, this is possible since the area is large, but as the tip is approached, the area is reduced and the curvature increased. We see process in the series of SEM micrographs. There appears to be a near perfect split in our split tip at low magnification, Figure 6(a). At a magnification of X95, the split appears well defined, but it is crucial to see this type of behavior at the aperture of the probe, rather than up the shaft. As we approach the probe aperture, we see certain imperfections, such as voids in the coating. At X2000 magnification, Figure 6(b), we see cracking and peeling, which presents a significant problem. Figure 6(c) shows the probe at X11,000 magnification, clearly indicating the we are dealing with a case of tensile stress. The aluminum film on the right side of the split tends to bow in a few spots. We also see from this micrograph that tensile stress will relieve itself by microcracking of the film and the peeling of the cracked surface from the substrate. The stress distribution in this film is anisotropic; there are cracking patterns that depend on the stress distribution.

The curling of the metal layer near the aperture, along with the observed cracking of the probe coating suggests the coating, a thin film of Al, experiences stress due to the differences in thermal expansion (thermal stress) between the Al and the silica fiber. In general, stress in films results from the differences in thermal expansion (thermal stress) or from the microstructure of the deposited film (intrinsic stress). At substrate temperatures less than 20% of the melting point, intrinsic stress due to incomplete structure ordering dominates. Intrinsic stress results from the microstructure created in the film as atoms are deposited on the substrate. Tensile stress results from micro-voids in the thin film, because of the attractive interaction of the atoms across the voids. Thermal stress occurs because film depositions are usually made above room temperature. Upon cooling from the deposition temperature to room temperature, the difference in the thermal expansion coefficients of the substrate and the film causes thermal stress.

The most common way for measuring film stress is by measuring the deflection (bowing) of a thin film substrate (beam or disc) on which the film has been deposited. This is not possible here, since the substrate is much thicker than the film itself, the substrate is coated on more than one side, and hence, no bowing seems to have occurred. Nevertheless, assuming knowledge of the mechanical properties of the substrate and film, film thickness, and the deflection, we can calculate the film stress. In particular, the film stress, \( \sigma_f \) for a film of thickness \( t_f \) and Young's modulus \( E_s \) on a substrate of thickness \( t_s \) and Young's modulus \( E_s \) curved with a radius \( \rho \) and distances from the neutral plane to the point in the film and substrate of \( Y_f \) and \( Y_s \) respectively, is given by:
\[
\sigma_t = \frac{t_E}{5\rho} \left[ \left( \frac{t_f}{t_s} \right)^2 + 6 \left( \frac{E_s}{E_f} \right) \left( \frac{Y_f}{Y_s} \right) \right], \text{ where } -\frac{1}{2} \leq \frac{Y_f}{Y_s} \leq \frac{1}{2}. \tag{6}
\]

The substrate stress (\(\sigma_s\)) is likewise given by:
\[
\sigma_s = \frac{t_E}{6\rho} \left[ 1 + 6 \left( \frac{Y_s}{t_s} \right) \right], \text{ where } -\frac{1}{2} \leq \frac{Y_s}{t_s} \leq \frac{1}{2}. \tag{7}
\]

Large film stresses often result in adhesion failure (de-adhesion), especially when the film has a high modulus or the thickness is large. Hence, we have identified two major contributors to our tensile stress problem:

1. Difference in heating and cooling rates of the substrate and film upon deposition; i.e., the difference in thermal expansion.
2. Film thickness regulation; i.e., the rate of film deposition.

The small size of the probe tip represents a particular problem, since its thermal mass is small – comparable to the thermal mass of the deposited film. This means that the tip end will heat significantly during the film growth process, from both radiative effects and energy carried by the metal evaporant, unless special care is taken to prevent it. Tip heating means that significant thermal stress will result when the tip plus film cool to room temperature.

We can estimate the temperature rise in the probe with a simple calculation. The first process that can heat the probe is energy deposited by the metal evaporant, which is given by the evaporation rate onto a flat, unilteld surface \(R\) (1 nm/s) the same distance from the source as the tip, an angle correction \(\cos(\theta+\psi)\) for the tip with half-angle \(\psi\) (6°) tilted up at angle \(\theta\) (45°), the heat capacity \(c\) (400 J/kg/K for Al), density \(\rho\) (2700 kg/m\(^3\)), temperature change \(\Delta T\) (800 K above ambient estimated by evaporant color), and area of the film \(A\) (at distance \(z\) from the tip):

\[
\text{Energy input} = R \rho c \Delta T A \cos(\theta+\psi) \text{ with } A = 2\pi z \frac{dz}{\cos\psi \tan\psi} \tag{1}
\]

The second process that can heat the tip is radiation from the thermal evaporant source. Radiative heating power is given by \(P = \sigma A \epsilon (T^4 - T_o^4)(SA)\), which is also proportional to the area. The emissivity \(\epsilon\) is approximately 0.06 for shiny aluminum and 0.8 for the glass fiber. The transition will take place in the first few nm of deposition. We calculate for a temperature of 930K, a solid angle of \(SA\approx 10^{-5}\), that the contribution from radiative heating into the same area as for evaporation is about an order of magnitude smaller. Both have the same area-factor, so will enter the equations similarly. Cooling is primarily by conduction up the fiber taper, as determined by:

\[
\nabla^2 T - \frac{\rho c}{\kappa} \frac{dT}{dt} = \frac{Q}{\kappa}, \tag{2}
\]

where \(\kappa\) (1.5 W/m/K) is the thermal conductivity of quartz, \(\rho\) the density, \(c\) the heat capacity, and \(Q\) the thermal energy per volume. In steady state, the time derivative vanishes. Since the taper is a cone to a good approximation, and since symmetry and lack of significant radiation (and no convection) implies we can convert the thermal problem to one of spherical symmetry, with the energy input per volume given by that in equation (1) scaled by the inverse of the fraction of solid angle taken by one tapered fiber: \(2/(1-\cos\psi)\). This assumes that the energy is uniformly input, rather than at the sides.
of the taper, but is justified by the relatively shorter lateral thermal times. The energy input in (1) is divided by the volume of a shell at a radius \( z \) to get

\[
\frac{Q}{\kappa} = \frac{R \rho c \Delta T \cos(\theta + \psi)}{\kappa (1 - \cos \psi) \cos \psi \tan \psi} \frac{l}{z} = D \frac{l}{z} = 633 \text{ K/m} \frac{l}{z}. \tag{3}
\]

Equation (2) in spherical coordinates becomes, for steady state and uniform in angle,

\[
\frac{1}{z^2} \frac{\partial}{\partial z} \left( z^2 \frac{\partial T}{\partial z} \right) = \frac{Q}{\kappa}. \tag{4}
\]

This is solved by a function of the form \( T = A/z + B + Cz \). We set the derivative equal to zero at the end of the taper \( L \) (0.5 mm) to indicate the reduction in heat flow at the end of the cone, and set the temperature at the end of the taper to ambient, \( T_0 \). This implies

\[
T = DL^2/2 (1/z) + T_0 - DL + D/2 z. \tag{5}
\]

Near the end of the fiber, the last 2 terms are small, and at \( z = 1 \) micron, the temperature rise is \( \sim 150 \) K above \( T_0 \).

When we cool the liquid nitrogen cold trap, we find that the temperature of the fiber holder \( T_0 \) decreases to between 120 and 150 K below ambient. Thus, the region near the probe tips during evaporation is at or reasonably close to room temperature during evaporation. This is what is required to minimize thermally induced stress.

We use the following protocol for fabricating the probes:

1. Cooling the tips as described in the paragraphs above, or coating in multiple steps, with a 2-3 minute cooling period between each step.
2. Depositing a very thin aluminum film near the tip, on the order of 10 nm. Thus, tensile stress is reduced by avoiding a large value for \( t_f \). Our substrate-film heating is also minimized, since the deposition duration is short. This also reduces the chance of shorting, discussed below.
3. Apply a thicker coating (100-200 nm) to the contact pads so that they will be reliable under repeated use.

These steps minimize the thermal stress by keeping the tip as close as possible to room temperature during the deposition as is possible, through cooling and reduced thermal input. The stress is less important for the contacts, since they are in the region where the fiber is its full size, with sufficient thermal mass to prevent significant thermal variation.

![Figure 7. The tip of a split-tip probe fabricated with the optimal procedure discussed in the text.](image)
The result yields well defined ‘split’ behavior in our probes with no sign of stress conditions previously observed. At greater magnifications (Figure 7), we are able to observe the detailed features of the aperture to display the consistency and control of both the split and the deposition of the material used (Al). We also observe residual material in the split of the probe, away from the aperture. This threatens the required isolation of the electrodes that we have deposited on either side of the probe, but is not unexpected.

Mathematically, one expects a perfectly-aligned deposition to uniformly \((\cos\theta)\) approach zero at the point where the probe surface is perpendicular to the evaporation source. Lack of isolation will result in the two sides shorting together. The effect is most dramatic very near the tip, where the distances involved are short. Figure 8 provides a detailed view of the split. The split is, in fact, not completely void, but contains small grains of material. The grains are sparse within the split and vary in size from a few nm to tens of nm. The fact that the material is sparse and composed of ‘balls’ and individual grains (not a relatively smooth coating) is likely due to Ostwald Ripening or coarsening. The metal nucleates as small, dispersed particles initially, but the smaller particles slowly disappear as materials 'evaporates' onto a few that grow relatively large. The smaller particles act as “nutrients” for the larger particles. As the larger particles grow, the area around them is depleted of metal. This is a spontaneous, diffusion process that occurs because large particles are more energetically favored than smaller ones.

Another factor that improves the electrical isolation is oxidation. Very thin metal within the split will be completely oxidized (if we use Al). This can be enhanced by exposing the probes to a few hundred mTorr of pure oxygen for \(\frac{1}{2}\) hour [x] as a preliminary to venting the system. We follow this process with Al probes.

**Probe Mounting**

The split-tip probe needs independent electrical contact to the two sides. Due to the concerns noted above, we need to be able to verify contact and lack of shorting between the two sides. Further, the probe must be compatible with mounting into a scanning proximal probe microscope. The latter entails mounting the probe tip onto the side of a quartz tuning fork (a few mm in length, with 32768 Hz free resonance) that is mounted to the microscope. To prevent shear from removing the metal layer near the contacts, the fiber must be held securely in place, without translation or rotation. Our system allows for these constraints by rigidly holding the fiber in a V-groove/clamp with 2 gold wires pressed against each side. This is shown in figure 9. This part can be translated and rotated to bring the fiber probe it is holding up against the tuning fork. Both are mounted to a glass plate that fits onto the scanning proximal probe microscope, so the operation can be performed conveniently away from the microscope under a dissection microscope. One the probe is against the tuning fork, glue is applied to the joint and the adjustments left fixed. We have found that the clamping of the fiber as shown in figure 9 does not impact the lateral force microscopy as used in NSOM [xi]. We have not observed any
significant differences in the resonance behavior of the split tips compared to uncoated or uniformly-coated NSOM probes either.

Figure 9. A photograph of the tip holder – a piece of glass shaped to hold the tip on a tuning fork (upper right portion), the Teflon holder on the upper left keeps the gold wires positioned for contact with the fiber. The fiber can be seen passing through the groove in the Teflon where it contacts the wires, and on to the tuning fork (partially hidden).

The operating sequence once the probe is mounted is to check that contact is established on each side by measuring the resistance between the wires on the same side of the probe with a multimeter. When both sides have contact, the resistance between the two sides is measured, and should be too large for the meter to register. Possible causes of a lower resistance include a twisting of the probe so that the split is shorted and a probe shorted during the deposition of the metal. This typically happens when there is an etching defect that leaves a mound or hollow on the taper near the tip. The geometry of the mound is such that metal can coat across the split on the edge of the mound. We have found that it is also possible to measure the resistance from one wire on the holder to the fiber coating itself, by using a thin (0.002 inch diameter) gold wire to make the contact to the coating. This contact is not as reliable as a fixed contact, however. Once the electrical
characteristics of the probe and connections are verified, a variable voltage is applied to the probe. In cases where leakage current through the solution is possible, the ground lead is replaced by the virtual ground of a high gain current preamplifier, to monitor the magnitude of any shorting current.

**Probe Use in a Near-Field Optical Microscope**

The split-tip probe can be used to fabricate nanoscale-sized regions of molecules that are aligned in the plane of the surface. A verification of this is to create a large region that can be tested for alignment in a standard optical microscope in polarization mode. A thin film of a water soluble PPV precursor Poly (p-xylene tetrahydrothiophenium chloride), 2.5% in water was diluted 1:4 methanol. Small chips of glass coverslip used as substrates were spin-coated at 500 RPM for 15 s, then at 2000 RPM for 60 s, then at 3500 RPM for 40 s. This differs from the sapphire used in the thickness studies, since the sapphire is also optically anisotropic, confusing the analysis of the film layer. The glass substrates are optically isotropic.

The samples were loaded into a custom NSOM with a split-tip installed, and the system brought into feedback. A region to orient the molecules was chosen from a topographic image created with the split-tip in shear-force height imaging mode, Figure 10(a). A large area of the surface was covered in several 4-micron-square scans, with exposures from a Photon Systems HeAg laser at 224.3 nm wavelength. Exposures varied from an average of 5.8 to 50 pulses per point, where the points were spaced by 40 nm, approximately the optical resolution of the probe. Each pulse was ~80 microseconds long and of 3 microJoules of energy. The pulse rate of the laser was 20 Hz. The size of the exposed region is consistent with deposition at all exposure times.

![Figure 10](image.png)

Figure 10. (a) Topographic image of the spin-coated glass surface 1 micron horizontal and 300 nm vertical, with a 200 nm gray range. (b, c) The region of molecular deposition is imaged with polarized microscopy. (b) Crossed polarizer configuration. (c) with the analyzer removed. The bars are 20 microns long.

After exposure, the sample was removed from the NSOM and developed in pure methanol for 30 s, rinsed in DI water, and blow-dried with dry nitrogen. Optical analysis was performed in a Nikon TE2000-U inverted optical microscope using a 40X, 0.75 NA
objective lens. Figure 6 shows optical micrographs of the region of deposited molecules. In the figure, the orientation of the split-tip should result in molecules aligned at about 45 degrees from vertical in the image, perpendicular to the edge of the region. The analyzer was set to pass light polarized vertically with respect to the image. When the incident polarization was set perpendicular to this, Fig. 10(b), the region without molecules appears dark, as expected for crossed polarizers, but the region with molecules appears bright. This indicates that the molecules have rotated the polarization of the light, which implies that the deposition is at least partially ordered; the molecules have a preferred orientation. When the analyzer is removed, the background is bright. The region of molecules now appears dark. This is due to absorption of light by the molecules. Since undoped PPV is a semiconductor with a bandgap just over 1 eV, it should absorb light in the visible wavelength range. The exposure time in Fig 10(b) is 8 times that of Fig. 10(a).

**Optical Characterization. DROP????**

The split-tip probe permits optical characterization of the deposited material. As has been mentioned, the probe must be asymmetric for use in lateral orientation. Our 'split-tip' probe resembles an NSOM probe, except that the metal coating on the outside is split into two parts that are electrically isolated. As such, it can be used as an NSOM tip for optical imaging as a characterization technique. The NSOM topography will also be used as the indicator of material deposition: both where it should and should not be. Polarized light will be used to detect sample anisotropy and hence the quality of orientation. We have been able to control the state of polarization of light emanating from a split-tip probe from linearly polarized (>100:1) in any direction, or circularly polarized. The large anisotropy expected in the deposited materials will permit the use of a simple anisotropy analysis system comprised of polarized illumination through the probe with an analyzer in the far-field collection system. For a conducting polymer film, this optical anisotropy data related to orientation should corroborate the electrical properties, and provide insights for the further improvement of the material. Specific questions include the spatial and size distribution of the ordered regions and a quantification of the charge carrier scattering at the interface of mis-aligned molecules. The spatial distribution of light emission would also be mapped for the light emitting polymers by simply collecting the light through the NSOM probe. The results of the optical characterization are available in a matter of minutes after deposition, making the evaluation procedure very simple. This, and the flexibility of distance adjustment, is why it is easier to develop the technique with a probe microscope.

**Summary.**

We have described the design and fabrication of a novel split-tip probe, which can be used to explore the possibility of depositing molecules with specific in-plane orientation that can be controllably varies over 10’s of nanometers. We found that the fabrication is significantly more difficult than standard NSOM probes due to the inherent unstable nature of the small metal plates under tension. Theoretical models of the heating during evaporation help to design a method for the fabrication of low stress films required in this unusual deposition geometry. The probes, once fabricated, perform well in topographic and optical microscopy in addition to the unique function enabled by the split tip.