Prism Liquid Measurements

Recently there has been interest in measuring the refractive index of liquids. Interest is driven by the semiconductor industry where liquid immersion lithography has become a popular way of printing smaller features on silicon wafers, and by the biological community interested in knowing the index of various aqueous fluids for studies of biological processes at the liquid-solid interface.

While it is possible to pour liquid into a cup and measure the reflected light from the surface as if the liquid were a solid piece of glass, there are some important complications when measuring liquids. For example, sample alignment can be more difficult for liquids, and external vibrations can cause the surface to ripple. These complications introduce uncertainty in the measured angle of incidence and loss of light at the detector due to scattering from a rippled surface. Also, since only a surface reflection is measured, the refractive index is generally only good to 2 or 3 decimal places since light does not pass through a bulk quantity of the liquid. This lack of optical path length also results in lower sensitivity to small k-values which determine absorption in the liquid.

Very accurate index measurements of “bulk” materials like glass and liquids are done using the prism minimum deviation technique. Figure 1 shows the principle of the minimum deviation method. Light is passed through a prism placed on a rotation stage. The stage is rotated until the angles of the entrance and exiting beams are equal. This is the minimum deviation condition. This technique is often used by glass manufacturers to determine the refractive index of various glass prisms. With accurate control of temperature, minimum deviation measurements can be accurate to better than 5 decimal places. Measuring the intensity of light passing through the prism at two different path lengths allows for accurate determination of the extinction coefficient, k.

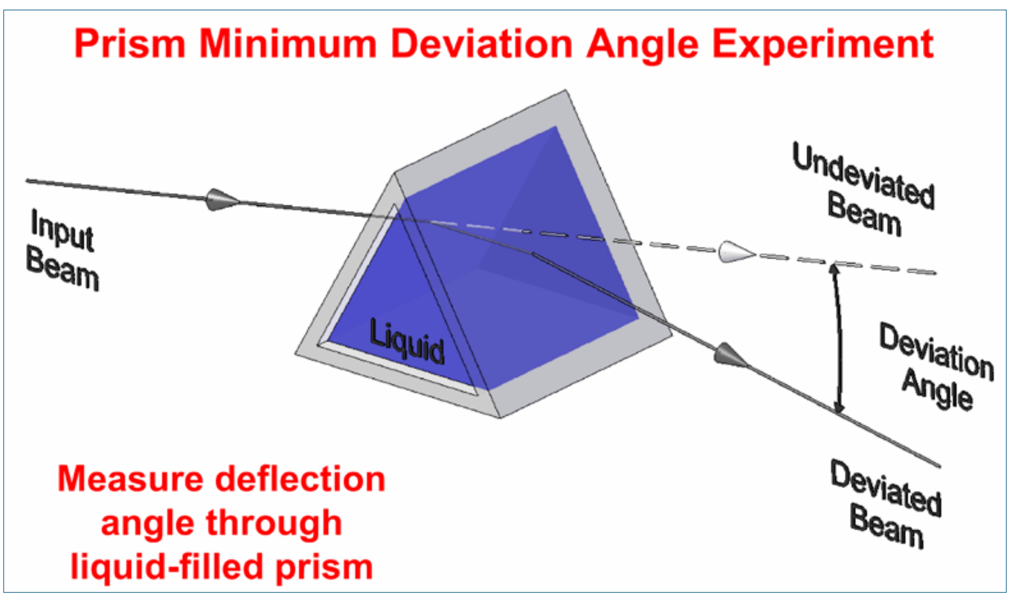

Figure 1. Geometry of prism minimum deviation measurement. Fluid is placed in a hollow prism and the deviation angle of the transmitted beam is measured. The fluid index is determined.

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Measurements can be made on liquids if hollow prisms are filled with liquid. This is done by machining a triangular prism of metal and fitting transparent windows. Window birefringence effects cancel out in the symmetric cell. This technique was used by NIST in the 1930s to determine accurate reference values for the index of water over a wide spectral range. Recent work at NIST by Burnett and Kaplan[1] has focused on determining the refractive index of both solids and liquids at deep ultraviolet and vacuum ultraviolet wavelengths.

The prism minimum deviation technique requires a highly accurate goniometer system to properly set the rotation angles of the prism and detector arm. Tunable wavelength selection is also desired if measurements are to be made at multiple wavelengths. Woollam VUV-VASE ellipsometers have both automated angle and spectroscopic capability, so implementing the minimum deviation technique is a natural extension of our existing ellipsometer technology. Figure 2 shows a liquid prism cell inside our VUV-VASE ellipsometer. Figure 3 shows the refractive index of water measured on the VUV-VASE. Excellent agreement was obtained with NIST values, which are shown for comparison.

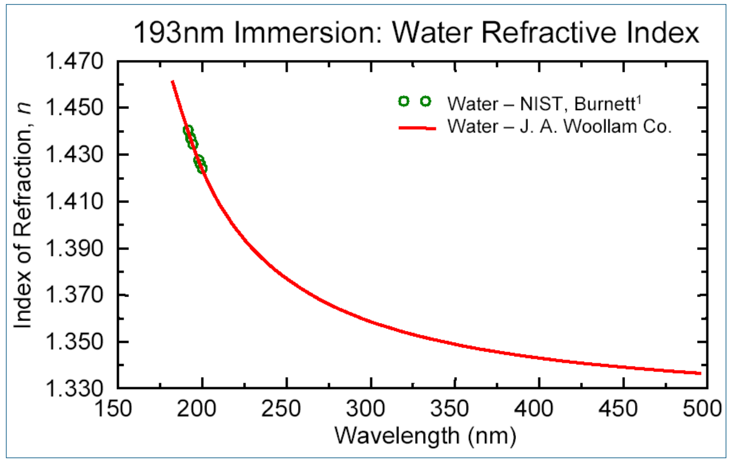

Figure 3. Refractive index of water at 21.5° C measured on the VUV-VASE. NIST reference values from Burnett are also shown. Excellent agreement was achieved with the NIST values.

Further Reading:

1. John Burnett and Simon Kaplan, "Measurement of the Refractive Index and Thermo-Optic Coefficient of Water Near 193 nm", *Proc. SPIE* **5040**, Optical Microlithography XVI (2003) 1742.
2. Roger H. French et al., "Immersion Fluid Refractive Indices Using Prism Minimum Deviation Techniques, *Proc. SPIE* **5377**, Optical Microlithography XVII (2004) 1689.
3. RonA. Synowicki, Greg K. Pribil et al., "Immersion Fluids for Lithography: Refractive Index Measurement Using Prism Minimum Deviation Techniques", *Semiconductor Fabtech*, 22nd edition, Henley Publishing, (2004) 55.
4. R.A. Synowicki, Greg K. Pribil et al., "Fluid Refractive Index Measurements Using Rough Surface and Prism Minimum Deviation Techniques," *J. Vac. Sci. B,* 22(6), (Nov/Dec 2004).

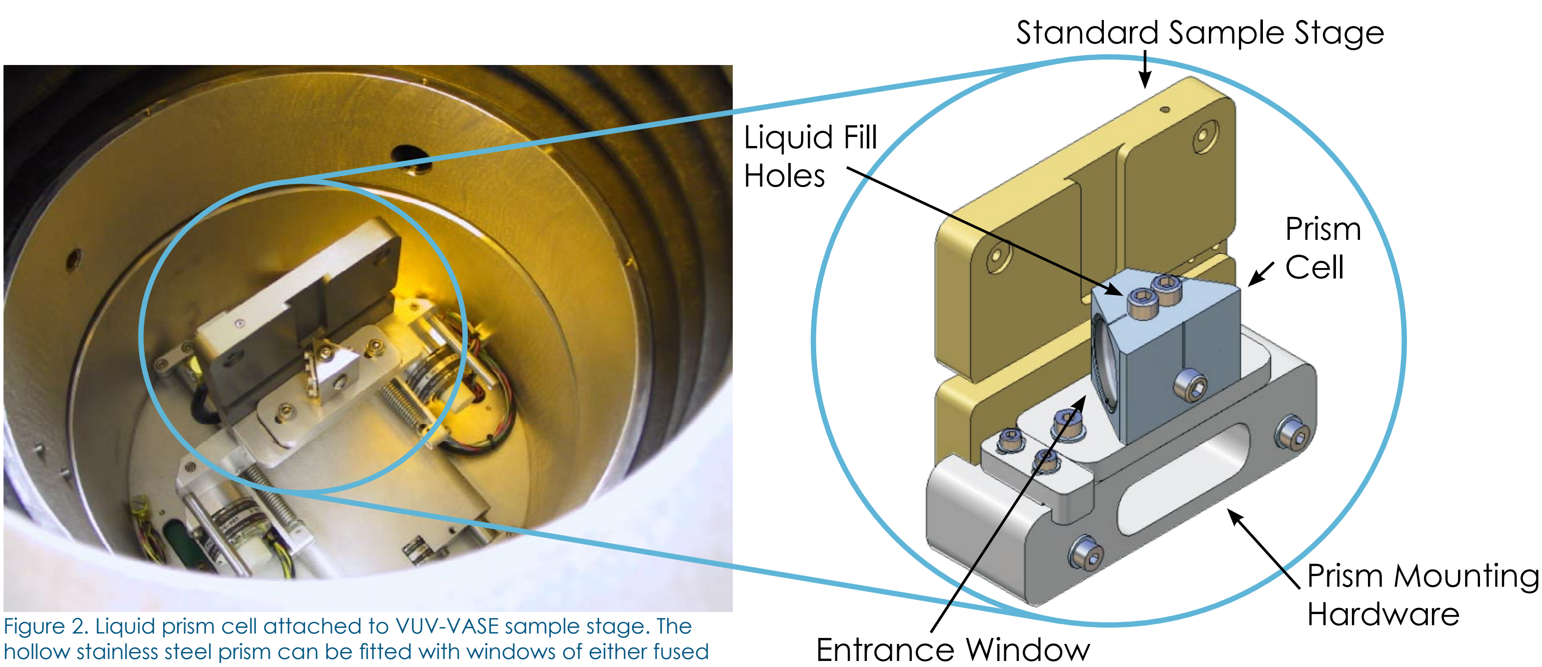

Figure 2. Liquid prism cell attached to VUV-VASE sample stage. The hollow stainless steel prism can be fitted with windows of either fused silica or calcium fluoride.