THz ellipsometry for the identification of liquids

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Liquids can be identified using their optical properties: the absorption coefficient and the refraction index. While in the visible and the neighboring ranges, the absorption of many liquids is very small and difficult to measure, and the span of the refraction index values is quite narrow, in the terahertz range these two optical parameters vary widely. This should allow a much more reliable identification. It is highly unlikely that two distinct liquids have the same optical properties at one frequency. Theoretically, such liquid pairs can be made intentionally, for instance by mixing three or more liquids, or might even be found accidentally. However, even if this can happen, it is virtually impossible to achieve a match for several frequencies, let alone for a continuous frequency interval. As measurements can be made over a wide frequency range, the identification of a liquid can thus be achieved with a high degree of reliability.

Our approach in measuring the optical properties of liquids relies on the use of a high-resistivity silicon prism, which is transparent in the THz range, and the measurement of the effect that the liquid-silicon interface has on the polarization of a THz wave, using a method called ellipsometry.

The ellipsometric method applied to our setup works as shown schematically in Figure 1. A collimated THz beam passes first through a polarizer placed in front of the silicon prism and becomes polarized linearly with an angle of 45° relatively to the main axes. The beam refracts upon entry in the prism and impinges on the upper surface at a fixed angle. There the beam suffers a partial reflection (total reflection if there is no liquid sample) and a phase shift occurs between the two orthogonal polarizations, transforming the linear polarization into an elliptical polarization. Another refraction at the exit from the prism brings the beam back to the direction it had before the prism. A second polarizer, which is mounted on a computer-controlled rotation stage, is then used to analyze the elliptically polarized wave. The signals are then input, recorded, and processed in a computer, and the optical properties of the liquid are output.

The source in our setup is a backward-wave oscillator (BWO) emitting in the range between about 400 and 700 GHz. Parabolic mirrors are used to collimate the beam and then refocus it on the detector. The silicon prism refracts the parallel beam and makes it possible for the THz radiation to interact with the liquid sample, placed on top of the prism.

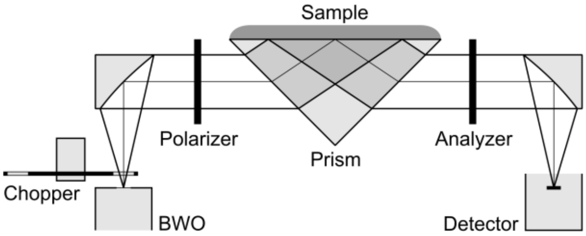

Figure 1. Schematic of the optical setup.

A large-size silicon prism is placed as shown in the figure. The upper surface is bordered by a rim that keeps liquid samples from spilling. The prism is mounted on a stage that allows movement in full freedom (two rotations and three translations). An optical sub-system, not shown in the figure, consisting of two parabolic mirrors and a small aperture between them, is used to make sure that the beam has the same path with and without the prism, and to check if the prism has rotated in any direction between measurements.

The optical signal is measured as a function of the analyzer angles. The results, a few examples of which are shown in Figure 2, are in the shape of sinusoidal waves with a period of 180°, whose parameters (amplitude, average, and phase) depend on the liquid. Each liquid is seen to have its own optical properties, which is a proof that the method can be used for liquid identification.

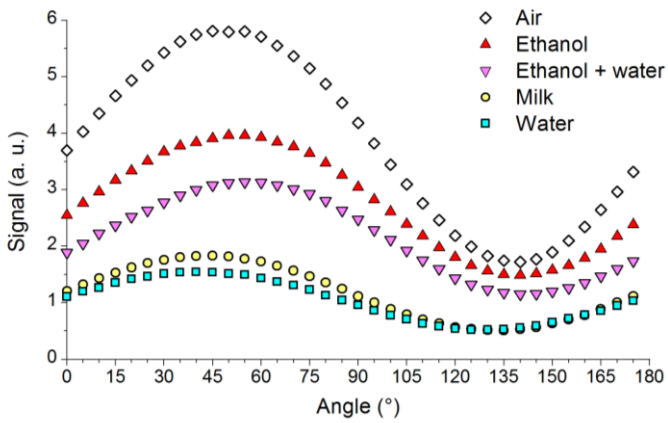

Figure 2. Output signals as a function of the analyzer angles.

The liquid marked as “ethanol + water” is a 50+50% mixture by mass.

The current stage of this research is at the point where the optical setup is finished and the programs for operating the setup are in place. Remaining to be done are the programs used to process the data and output the pair of optical constants of the liquid.