Noncontact single optical pulse method to measure cell membrane properties

David C. Clark and Myung K. Kim*

Digital Holography and Microscopy Laboratory, Department of Physics, University of South Florida, 4202 E. Fowler Avenue, Tampa, Florida 33620

**Corresponding author: mkkim@usf.edu*

Abstract: A capillary wave response is induced by an optical pressure pulse and tracked by microsecond-resolved digital holographic phase imaging to determine fluid surface properties. The method will be applied to the biological cell membrane.

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1. Introduction

Interfacial analysis is a valuable tool in areas of soft matter physics, chemistry, and biology. In fact, many surface energy measurement techniques have been employed for their varying degrees of improvement in accuracy, precision, or adaptability. Most of these tend to be invasive to the interface and suffer from an inability to make measurements within an intact system [1]. We introduce a noncontact purely optical approach to measuring the localized surface properties of an interface within a system using a single optical pressure pulse and a time-resolved digital holographic quantitative phase imaging technique to track the propagating nanometric capillary disturbance. We demonstrate the proposed method's ability to measure the surface energy of deionized water, methanol, and chemical monolayers formed by surfactants with good agreement to published values. The development of this technique boasts immediate application to static and dynamic systems and near-future applications for living biological cell membranes.

2. Theory

The initial deformation is a direct result of the conservation of photon momentum as the photon encounters a boundary of differing refractive indices as described in [2]. The dispersion relation for capillary waves at the interface of two media is described by [3],

$$\omega^2 = \kappa^2 \left(\frac{\sigma \kappa}{\rho + \rho_a} \right)$$

where ρ and ρ_a are the densities of the lower and upper fluids, respectively, κ is the angular wavenumber, and σ represents the surface tension between the fluids. For the present case of the air-liquid interface ρ_a can be dropped since $\rho_a << \rho$ and by substituting the phase velocity, $v = \omega / \kappa$, the relation can be written succinctly,

$$v = \sqrt{\frac{\sigma \kappa}{\rho}} .$$

In our experiments, we track the single-pulse capillary wavefront position as a function of time to determine a velocity and therefore the surface tension of the interface. This wavefront is visible in fig. 2 as a small trough propagating away from the origin.

3. Methods

The apparatus consists of a Mach-Zehnder interferometer for holographic phase imaging and an integrated pulsed excitation arm as described in [2]. The diagram is shown in fig. 1 with a close-up view of the dual-beam sample region. The captured holograms are processed by our LabVIEW personal computer platform for phase

reconstruction based on the angular spectrum method [4]. Due to the radial symmetry of the response structure, the raw phase image is azimuthally averaged to greatly improve measurement and tracking precision as described in [5].

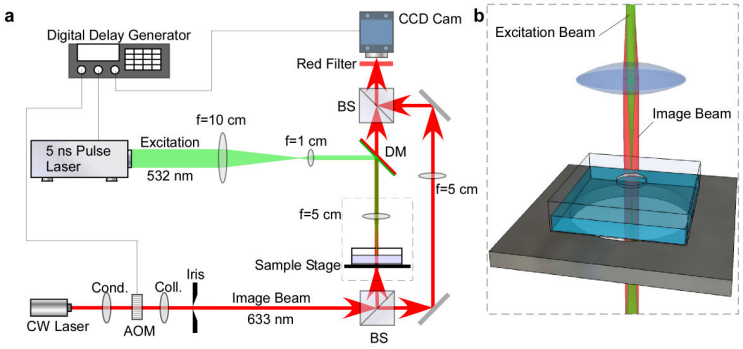

Fig. 1. Experimental apparatus. Pulsed excitation beam (green); Imaging beams (red); Microscope Objective (MO); Beam Splitter (BS); Dichroic Mirror (DM); Acousto-optic Modulator (AOM).

A digital delay generator controls precise timing of both excitation and imaging. Prior to delivery to the system, the imaging beam is condensed through an acousto-optic modulator (AOM) which, during triggering, diffracts the imaging beam through a collimating lens and iris. The pulse delay generator sends a 5 µs square pulse signal to this AOM shutter system at specified delay times relative to the excitation pulse. This delivery method produces the short exposure images required for this study without sacrificing phase quality as would be likely if a pulsed imaging beam were used instead.

4. Results and discussion

We first characterized our technique for known substances, DI water and methanol. Our measured surface tension for DI was 72.9±.6 mN/m where the tolerance here represents the standard deviation of repeated trials. For methanol we have measured a surface tension of 23.8±.3 mN/m. Next we measured the surface energy at the solution-air interfaces of 3 mM and 6 mM SDS concentrations in DI water with results of 50.1 mN/m and 38.9 mN/m, respectively. These values (fig. 3) are within the expected range for typical stock solutions at these concentrations.

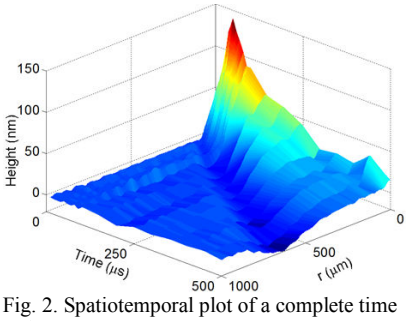

Fig. 2. Spatiotemporal plot of a complete time series.

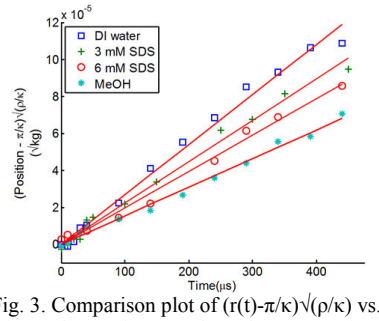

Fig. 3. Comparison plot of $(r(t)-\pi/\kappa)\sqrt{(\rho/\kappa)}$ vs. t for each sample type where the square of each slope is equal to the surface tension.

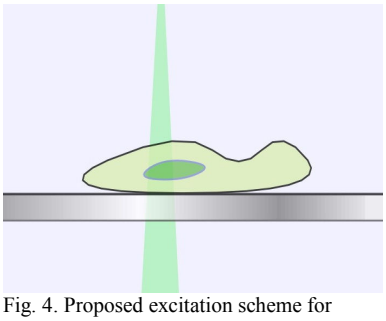

Fig. 4. Proposed excitation scheme for adaptation to biological cells.

The surface energy of biological cell membranes and systems has long been a topic of interest and studies continue to emerge as modern techniques prevail. Of particular need are techniques that can perform this analysis noninvasively in living cells as they undergo natural processes. It is our near-future goal to adapt this process for application to intact biological systems and measure live cell membrane surface energies (fig. 4).

5. References

[1] E. I. Franses, O. A. Basaran, & C.-H. Chang. "Techniques to measure dynamic surface tension," Curr. Opin. Colloid In. **1**, 296-303 (1996).
[2] D. C. Clark, and M. K. Kim, "Time-dependent Surface Response of Fluid to Transmission Optical Pressure Impulse," in Digital Holography and Three-Dimensional Imaging (Optical Society of America 2012).
[3] L. D. Landau, and E. M. Lifshitz, *Fluid Mechanics* (Pergamon Press, London, 1959).
[4] M. K. Kim, "Principles and techniques of digital holographic microscopy," SPIE Reviews **1**, 018005 (2010).
[5] D. C. Clark and M. K. Kim, "High-precision method for measuring photothermal properties of transparent media with digital holography (Invited Paper)," Chin. Opt. Lett. 9, 120001- (2011).