MICROCOMPUTER ENHANCED OPTICAL INVESTIGATION OF SPREADING
AND EVAPORATIVE PROCESSES IN ULTRA THIN FILMS

Progress Report

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	1
REVIEW OF PROGRESS	1
LIST OF PUBLICATIONS/PRESENTATIONS	5
BUDGET INFORMATION	6
FIGURE (1)	7
FIGURE (2)	8
APPENDIX A	} <i>removed and cycled separately</i> -
APPENDIX B	
	A-1
	B-1

ABSTRACT

The general objective is to determine the heat transfer characteristics of evaporating ultra-thin films. The immediate objective is to develop a microscopic image-processing system (IPS) to measure the film thickness profile. The IPS has two parts: an image analyzing interferometer (IAI) and an image analyzing ellipsometer (IAE).

An IAI was designed and used to measure the thickness profiles of an extended meniscus in the contact line region of a completely wetting film of Octane on an inclined, flat plate. The equilibrium profile agreed with theoretical predictions of the width of the transition region, the curvature, and the thickness of the adsorbed film. The effect of transport processes on the thickness profile agreed with previous theoretical models. We find that the convenience and efficiency of microcomputer enhanced video microscopy naturally leads to a better understanding of the transport processes in the contact line region. We also find that the processes of change-of-phase heat transfer and fluid flow in thin films are intrinsically connected because of their common dependence on the intermolecular force field and gravity. The redesign of an image analyzing ellipsometer (IAE) has been completed and the system is being built and evaluated.

REVIEW OF PROGRESS

The updated design of the combined IAI-IAE is given in Figure (1). The design and use of the IAI are discussed in Part (A) whereas, the design of the IAE is discussed in Part (B). A conceptual drawing of the location of the meniscus is given in Figure (2).

PART A: IMAGE ANALYZING INTERFEROMETER SYSTEM SET-UP AND USE

An image analyzing interferometer system was designed, assembled and used. The complete details of the system are given in Publications (P4 and P5) listed in the Publications List. An Abstract from Publication (4) is attached as Appendix (A). An extended Abstract outlining the results of transient studies is attached as Appendix (B). In these studies, the thin film itself acts as the interferometer since light is reflected from both the liquid-solid and liquid-vapor interfaces. Briefly, the system consists of a 16 MHz IBM-PC286 Clone computer equipped with a real time frame grabber board [DT-2851 from Data Translation]. The frame grabber acquires an image from a CCD camera connected to a WILD-M420 Macroscope. This analog signal is digitized by conversion to a voltage. The acquisition of 490 (vertical) x 512 (Horizontal) space pixels and assignment of one of 256 possible grey values to the reflectivity recorded by each pixel representing an intensity value is simultaneous. This data is stored automatically in the form of a 512 x 512 matrix. Each element of the matrix represents an intensity (grey) value [0 = Black, 255 = White]. Thus a macroscopic image already magnified considerably by the macroscope is divided into microscopic spatial units called pixels, which act as individual, simultaneous light sensors. Each picture takes 256 kilobytes to store and can be displayed, filtered and enhanced to improve the Signal/Noise Ratio. A 122 Mb Hard Disk and a tape back-up was installed in the computer to accommodate the high number of pictures. [Each picture provides data on 1/30th of a second in time.] To improve the Signal/Noise ratio the picture elements can be averaged spatially [if the picture does not vary greatly in one spatial direction, e.g., in the parallel interferometric fringes usually obtained when a liquid spreads on an inclined rectangular flat plate] or if the variation with time is sufficiently slow consecutive picture frames can be averaged [e.g., if the picture does not change in 1 sec, 30 frames can be averaged]. To improve the speed of the enhancing operations an optional DT-2858 Frame Processor and a 80286 Math Co-processor were installed. The installed image-processing hardware can be easily accessed by PC Semper or DR-IRIS software. The whole process is thus

highly automated, requiring user intervention in only the writing of software commands so that different systems can access data and use the relevant fluid properties required.

Data on the extended meniscus profile was obtained using a glass cell which could be easily cleaned. The extended meniscus includes both the intrinsic meniscus and the adsorbed thin film regions. The data presented in (P4-P6) demonstrated the capability of the system.

The intensity plot was compared with excellent agreement in a separate study by the simultaneous use of a scanning microphotometer and the image processing system. There are advantages and disadvantages of the IAI system relative to the possible use of the scanning microphotometer as an alternative. The Signal/Noise ratio could be enhanced in the microphotometer system, but it is also prone to more errors due to its inherent reliance on a scanning table. Furthermore, data acquisition with a microphotometer is not simultaneous and involves subjecting the fluid to light and motion (due to the scanning) for the period of the measurement and the set-up. This precludes its use in transient experiments and increases experimental errors especially when used with highly volatile and/or viscous fluids. Further, after data acquisition on a strip-chart recorder, the photometer requires considerable user intervention to generate film thickness profiles. We believe that the recently designed IAI is the better choice. Because the image processing system built captures instant [1/30th of a second] images, it is much easier to use, easily automated and ideal for use in transient experiments. To demonstrate its capability for acquisition of transient data we also used the system to study the flapping [oscillatory to and fro motion] of the contact line [and hence the fringes] in a heat transfer experiment conducted in a separately designed capillary cell. The images were captured by continuously recording on a high quality, excellent resolution 3/4" S-VHS VCR [Sony VO-9600]. The VCR which has a B/W resolution of 300 lines (horizontal) was also connected to a Sony FCG-700 Frame-Counter, so as to superimpose each frame with a permanent frame identification number. Thus, the tape could be replayed later and

various frames could be captured and analyzed. Frames 1/30th of a second apart in time were analyzed and used to measure the movement of the contact line. The procedure also tested the system's performance when images recorded on a VCR were used [as opposed to live capture of images]. It was found that for this high quality VCR the Signal/Noise ratio [48dB for the VCR itself] was still suitable. Other low quality VCRs performed miserably with respect to this criterion. The initial transient results are presented in P6 and Appendix (B).

To summarize the image processing system designed provides an easy to use, economical and versatile system capable of acquiring both transient and equilibrium data with minimum disturbance to the system. The combination of easy data acquisition, improved data resolution, automatic data analysis and adaptability make this system an excellent choice for the proposed study. Additional details of these results are presented in (P4-P6).

PART (B) IMAGE ANALYZING ELLIPSOMETER

The **image analyzing ellipsometer (IAE)** has been redesigned, and is in the process of being rebuilt and tested. A simple diagram of the new system is given in Figure (1). The IAE is a rapid full-field imaging technique developed for high spatial resolution that will enable measurement of the changes in the thin liquid film thickness profile associated with fluid flow and evaporation. Conventional ellipsometry is limited to single detector operation which requires slow scanning of the sample to create two-dimensional images of the liquid film. However, greatly increased speed and resolution are required to study changes in the liquid film profile in the transient state. Therefore, the IAE presented in Figure (1) was designed.

To utilize multiple simultaneous detectors a Polarizer, Compensator, Specimen, and Analyzer (PCSA) ellipsometer arrangement is used in an intensity (radiometric) measurement mode rather than in a conventional null measurement mode. Eq.(1) gives the intensity of the light leaving the analyzer.

$$\begin{aligned}
I(A) = & (G^2/2) \{ [1 + (\cos 2C)(\cos 2(P-C))] \cos^2 A \tan^2 \psi \\
& + [1 - (\cos 2C)(\cos 2(P-C)) \sin^2 A] \\
& + [\sin 2C (\cos 2(P-C)) \cos \Delta - \sin 2(P-C) \sin \Delta] \sin 2A \tan \psi \} \quad (1)
\end{aligned}$$

When the polarizer angle, P, and the compensator angle, C, are fixed, the ellipsometric parameters Δ and ψ can be evaluated using only intensities recorded at known analyzer angles, A. Since the analyzer settings are independent of the film parameters, measurements may be made using multiple detectors, thereby obtaining full-field imaging. A minimum of three precise intensity measurements at the same film field location are required to define the three unknowns in Eq. (1) at selected analyzer angles: G (the system gain); Δ ; and ψ . Therefore, the computer controlled stepping motor is needed. Multiple field locations are obtained using the pixel array in a video camera. The image processing system automates data analysis.

The IAE described in our initial report, which was designed for proof of principle testing, was configured using an available null ellipsometer modified with laboratory optical equipment. However, the images were small and insufficient for adequate analysis. Therefore, we added an autocollimator to obtain accurate alignment and a long working distance microscope to improve resolution and magnification. Using this design, we have obtained a qualitative proof of principle. We are currently working on the computer control system for the analyzer so that precise intensity measurements at three selected analyzer angles can be obtained for analysis and quantitative concept evaluation.

LIST OF PUBLICATIONS/PRESENTATIONS

- P1) "Fluid Flow in Ultra Thin Films" M. Sujani and P.C. Wayner, Jr., Presentation 167C-b, 1989 Annual Meeting of A.I.Ch.E., Nov. 5-10, San Francisco, CA.
- P2) "Microcomputer Enhanced Optical Investigation of Transport Processes in Thin Liquid Films", M. Sujani and P.C. Wayner, Jr., pp. 79-86, DOE CONF-9005183, Proceedings of Eighth Symposium on Energy Engineering Sciences, Argonne National Laboratory, Argonne, IL, May 9-11, 1990.

- P3) "Microcomputer Enhanced Optical Investigation of Spreading and Evaporative Processes in Ultra Thin Films", P.C. Wayner, Jr., M. Sujanani and A.H. Liu, DOE Report DOE/ER/14045-1, January 1990.
- P4) "Interfacial Phenomena in an Evaporating Thin Film", M. Sujanani, Ph.D. Thesis, Rensselaer Polytechnic Institute, Troy, NY, 1990.
- P5) "Microcomputer Enhanced Optical Investigation of Transport Processes with Phase Change in Near-Equilibrium Thin Liquid Films", M. Sujanani and P.C. Wayner, Jr., Accepted for publication in J. Colloid and Interface Science.
- P6) "Transport Processes and Interfacial Phenomena in an Evaporating Meniscus", to be presented at 1991 ASME/AICHE National Heat Transfer Conference, Minneapolis, MN.

BUDGET INFORMATION

We do not anticipate an unexpended balance at the end of the current funding period. The principal investigator spent the following time on the contract: Summer 1989 (1 month); 1989-90 academic year (9%); summer 1990 (1 month); Sept. 90 - Dec. 90 (10%). During the final six (6) months of the second year, he will spend 10% of his time on the project.

Figure 2 Completely Wetting Liquid on an Inclined Plate

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