Synopsis

Interest in structure and properties of liquids and soft matter has a long and rich tradition in physics. Optical probes, based on diffraction and scattering of light, are extensively used to investigate diverse properties of matter in various forms. Such studies not only provide information on characteristics of materials but also, simultaneously, improve our understanding of the behavior of light. In this thesis, broadly titled, "Optical probes for liquids and wet foam", while the physical properties of liquids and liquid films have been investigated by generating surface capillary waves and then probing the resultant phase grating by optical diffraction; the characteristics of wet foam, has been addressed through optical imaging and light scattering techniques.

Chapter 1 is primarily introductory. Here, we first, briefly recapitulate Fraunhofer diffraction of light by capillary waves formed on a liquid (water) surface. The basic theoretical analysis behind this diffraction phenomenon, using standard Fourier optics, is summarized in order to provide adequate background for subsequent discussion. In the second part of Chapter 1, we introduce a physically interesting soft material—Gillette shaving foam—which is categorized in the literature as wet foam. The interest in wet foam arises from the intrinsic complexity in its structure and dynamics, which makes it a fairly difficult system to work with. However, wet foam has immense potential for unravelling new phenomenology in the context of soft

matter. In our brief preamble, here, we look at the basic structure and properties of wet foam. As Raman spectroscopy is one of our important diagnostic tools, we also provide a brief introduction to Raman scattering phenomenon.

Chapters 2–4 of this thesis present the work on optical diffration by liquid surface capillary waves. The work on Gillette (wet) foam has been discussed in Chapters 5–7.

Chapter 2 describes a simple experiment on diffraction of monochromatic light by *interfering* liquid surface waves. The surface wave profile, which acts as a reflection phase grating for the incident light, is generated by electrically driven vertical exciters. These exciters are slightly immersed in the liquid and placed at a small distance apart. The intensity distribution in the diffraction pattern, calculated theoretically, is found to tally well with observations. Though invisible to the naked eye, we put forward a technique to 'see' interfering liquid surface waves, optically, through the characteristic features of the diffraction pattern. A combination of simulation with the realistic parameters involved and experiment is proposed to trace out the surface wave profiles in various situations (e.g. for one or more vertical exciters in a line or at the vertices of regular polygons). In addition, we also measure the amplitude, wavelength and phase velocity of the surface wave, which propagates along the line joining the exciters.

In **Chapter 3**, we revisit the classical method of probing inherent properties of liquids using optical diffraction by surface capillary waves. The measured value of the surface tension and the spatial damping coefficient (related to viscosity) of a variety of liquids when compared to the respective values known from other sources,

summarily establish the efficacy and accuracy of our approach. The advantage of having a single set-up for measuring both these properties need not be further emphasized.

Chapter 4 investigates, both experimentally and theoretically, an interesting aspect of the dispersion relation for the capillary wave on a liquid film formed on the surface of an immiscible liquid (films of n-n dimethyl aniline, o-xylene and kerosene on water). Here, we deal with the ω–K dispersion relations, surface and interface modes, interfacial tension and related issues for liquid films on liquid in some detail.

On the whole, our observations and analysis in the Chapters 2–4 seem to support the claim that the simple experiment on Fraunhofer diffraction by liquid surface waves is capable of providing a wealth of information on properties of liquids, liquid films as well as the surface waves, in a non-destructive way.

The next three chapters of the thesis present the work on wet foam. Foam is a dispersion of gas bubbles in an aqueous solution of surfactants. It consists of a collection of gas bubbles surrounded by thin liquid films. With time, the spherical bubbles in fresh foam grow in size and take the form of polyhedra while minimizing the energy of the system. Furthermore, the liquid between the bubbles can drain out along the liquid channels (Plateau borders) in response to gravity. The adjacent bubbles coalesce if the liquid film becomes too thin. The evolution of the bubbles in foam with time (ageing of foam) can be described by the above three mutually coupled mechanisms: coarsening, drainage and coalescence.

Chapter 5 discusses the coarsening of bubbles in wet foam. Using microscope images, we have estimated the evolution of the Sauter mean diameter of the bubbles

in wet foam, at specific time intervals, over a duration of 3 days. The bubble size distribution has been estimated from each image frame for the entire time scale. A possible way of analyzing such distributions in bubble size, statistically, is proposed and discussed.

Drainage of water from wet foam, with ageing, has been discussed in **Chapter 6**. Using Raman spectroscopy, we have shown that in addition to free water molecules, which drain out with aging of foam, water clusters of only a few water molecules are also present in foam. We have analyzed the rate of drainage with the existing theory available in the literature. A comparison of our experimental observations with the results obtained using self consistent field calculations reveal the presence of bound water clusters in the form of tetrahedral structure (like ice) in Gillette shaving foam.

Finally, we provide the gross properties of wet foam in light of its molecular structure, which changes with time. In **Chapter 7** the molecular structure of Gillette foam has been studied to some extent. We correlate the internal stress and the characteristics of molecular vibrational modes in wet foam. Using microscope images, we estimate the average size of the bubbles in wet foam, at specific time intervals, over a duration of twenty four hours. Raman spectra are also recorded at the same time intervals, over the same time frame. We show that the internal stress, which originates from the macroscopic structural change of foam with ageing, can be related to the observed Raman shift of the low frequency methylene rocking mode of the constituent surfactant molecules in foam. We also show the capability of the Raman spectroscopy to reveal the crystallinity in foamy materials, when studied for

a longer period of time.

Chapter 8 discusses possible directions for future projects.