Chapter 1 Introduction

1.1 Organic Thin Films

The polymer thin film industry has grown very rapidly in recent decades affecting diverse commercial sectors, such as electronics, biotech. Thin film processing is essential to the success of the massive semiconductor and microelectronics industry and to the growth of the emerging opto-electronics and biosensor industries.[1] The techniques are widely employed for fabricating coatings to produce optical elements, to improve machine tools, and to form protective and anticorrosion layers on many components.[2]

Thin organic films are important for microelectronic devices. Thin conductive, semi-conductive, and insulating films of metal, ceramics, and polymers are used in conjunction with photolithography to create integrated circuits with active and passive devices. Nanometer thin silicon dioxide films are used in n-MOS and p-MOS integrated circuits, multi-chip module and photovoltaic fabrication as interlayer dielectric for metal-insulator structures.[3, 4] Such thin films must satisfy a large set of rigorous chemical, structural, and electrical requirements. Film composition and thickness must be rigorously controlled to facilitate etching of sub micron features.[3, 4] The fast growth of sophisticated processing methods and the ever-increasing complexity of new materials and devices require fundamental understanding of thin film processing. This has placed new and premium demands on engineers and scientists to develop and employ diagnostics to understand these structures and to monitor and control them in the fabrication line.[2]

An advantage of thin organic films is that they are highly selective and highly sensitive to particular species and can be tailored with desired functions, bio-reactive properties and incorporated into electronics, optical and electrochemical devices. The molecular dimensions of the organic films make the development of sophisticated detection systems possible. The operation of biosensors can be divided into three main events: recognition, perturbation, and transduction. Recognition should be both specific and selective. Once the molecules are attached to the recognition site, a detectible

physical change is triggered. The triggered change can be detected and analyzed by an instrumental arrangement.

The development of thin polymer films that are suitable for the fabrication of high-speed integrated optical devices is presently a major focus of research in nonlinear optics.[5, 6] Polymer materials have been demonstrated to possess large nonlinear optical (NLO) activity in contrast to traditional inorganic materials.[7] Their intrinsic low dielectric constant, easy processing and compatibility with microelectronic processes are the other major advantages of the polymers. Significant progress in device design and architecture with implementation of poled polymers into prototype electro-optical devices has been reported recently.[8] A common method of poling polymer films is the static electric field poling and the corona poling at elevated temperature close to polymer glass transition temperature (T_g).

There are numerous thin film thickness measurement techniques. Ellipsometry can determine both the refractive index and the thickness when film thickness is above 50 Angstroms. An accuracy of ~2A in detecting thickness differences with a lateral resolution of about the size of a laser spot was reported for ellipsometry.[9] Another optical microscopy, Nomarski microscopy, can obtain thickness with accuracy about ~30A and lateral resolution of 1 μm.[11] Rothenhasler utilized plasmon-surface polarization microscopy to measure film thickness by with the sensitivity of ~ 1A with lateral resolution of 1μm.[10] The most detailed and accurate information on thickness comes from x-ray reflectivity. The reflectivity method provides the information on the complex refractive index and the roughness of the film.[11] Contact angles with different liquids are measured to evaluate wetting properties, surface-free energy, uniformity, and to get information on the surface order. Electron spectroscopy for chemical analysis (ESCA) is used to study surface composition and monolayer structure. Surface imaging techniques such as AFM and SFM are used to study surface topography. However, these methods have reduced accuracy with thickness larger than 200nm. For instance, the characteristic thickness of dielectric thin films in microelectronics ranges from 10 nm to 1 μm. There are other limitations in the application for these techniques for industrial applications. X-ray reflectivity and ellipsometry cannot be economically applied to record in situ thin film property changes because of the time required to obtain the

measurement. A differential interferometer is good to measure "change" in thickness. Reflectivity/ellipsometry gives absolute value.

There are several methods for determination of optical properties of thin films. Most methods are based on spectrophotometry, interferometry and polarimetry. The optical measurement for this study is differential interferometer with a resolution of about 0.05nm and a larger dynamic range of film thickness from 5nm to over 10 μm. The largest thickness measured will be limited more by the quality of the film (i.e. stress and smoothness) and temperature uniformity rather than the measurement method. Besides the larger measuring range, differential interferometry can measure the dynamics due to the fast response and therefore is very useful to monitor and control the real-time properties changing of thin films.

1.2 Electro-Optical Studies

The field of nonlinear optics became of considerable interest in the 1960s with the development of promising organic molecular and polymeric materials.[12, 13, 14] Nonelinear optical materials are expected to have a wide range of applications in photonic technology including harmonic generators, optical computing, telecommunications, laser lithography, image processing, switching, sensors, and overall photonic transmission. Recently, a great interest in organic polymers has developed due to their low cost of fabrication and greater compatibility with desired substrates as well as tremendous possibilities for tailoring structures with high mechanical strength and environmental stability. However, there are some drawbacks of poled polymers. Thermal stability is one of the major problems. The orientation decays with temperature because the polar structure is not in thermal equilibrium. This degrades the reliability of poled polymers in practical applications. Currently, there are mainly two approaches to solve the problems. One is to choose high glass transition temperature polymer that shows little relaxation at room temperature.[15, 16] The other is to freeze the molecular orientation after poling by cross-linking.[17] The rigid cross-linked structure suppresses relaxation.

It has been more than fifteen years since the first electrical field poled second-order nonlinear polymers were reported.[18] During this period a wide variety of polymeric systems have been formulated and investigated. Most of the previous work concentrated

primarily on the polymer systems and the development and decay of the electric field induced ordering.[5] Others have focused on the relationship between the physical and chemical properties of second-order nonlinear polymers and their potential applications in electro-optical and frequency-doubling devices.[12] Now, much of the current work in this field is motivated by an attempt to find practical polymeric materials for these applications.

Several approaches have been used to induce organic thin film polar order. The polar structure is attained with the orientation of the chromophores in the electric field around glass transition temperature. Interdigitated [12] and coplanar[5] electrodes can be used where one desires the polar axis to lie in the plane of the thin film being poled. The thin polymer film can be formed as a "sandwich" between two parallel conducting plates in which case the polar axis is perpendicular to the film's plane.[19] Charge injection can also occur when parallel plate electrodes are used, and pinholes can substantially reduce the magnitude of the field that can be applied. High field strengths can be obtained using electrode poling provided careful attention is given to material purity, dust-free thin-film processing, and electrode design. Electrode poling is compatible with electrooptic and second harmonic device processing requirements. The most commonly used electrical field poling technique for polymeric systems is corona poling. This technique has been used for poling second-order nonlinear polymeric systems both at room temperature[20] and at elevated temperature.[21] Field across the polymer film exceeding 4MV/cm can be obtained in this way.[22] Such high fields are difficult to achieve using electrode poling. In most cases, electric field poling is done at a temperature near T_g. Recently, Tasaka invented non-electrical poling of novel ferroelectric polymers. This poling method utilizes "surface energy poling" and takes advantage of the energy difference between the top and bottom surface of a polar aggregate to form a remnant polarization. This poling method was proven to be effective for homogenous structures such as polythioureas, polyvinylfluorides.[23] Due to the different methods of poling, Paresh investigated the influence of poling methods on the orientational dynamics of 2-methyl-4-nitro-aniline in poly (methyl mehtacrylate) by comparing corona discharge and contact electrode poling techniques. Results show that under the same conditions, corona poling creates a higher alignment of molecules in the direction of the field.[24]

In this study, we probe the electro-optical properties of ultra thin organic films using electrode poling. An AC electric field is applied to pole Polypropylene oxide (PPO) at room temperature above its T_g (about -60^oC). PPO is a complex liquid rather than a solid. The thermal activity of liquid molecules dramatically reduces the response time of PPO to the electric field. However, the interaction between electric field and polymer molecules is not strong enough to break the covalent bonds in PPO molecules. Therefore, PPO shows long distance order under electric field even at temperatures above its T_g. Usually other polymers have higher T_g than room temperature. To increase the activation of polymer molecules, polymers are heated to their T_g while an electric field is applied and then cooled down with the electric field on to freeze the polarization.[29] The film thickness is less than 300nm, significantly smaller than reported in literature. The interfacial mobility in the thin film allows for faster dynamics and lower poling field. The NLO activity of poled polymer originates from the molecular alignment of these polar molecules by electrical field. Highly efficient poling is necessary to realize large NLO activity. For the first time, a fast response and second order harmonics generation of organic, polymeric film is observed at very high frequency range.

We also observe the Kerr effect in PPO film. The electric birefringence or Kerr effect is a very powerful experimental method usually used to obtain information about molecular structure for molecules under the influence of a strong electrical field.[25, 26] In particular, the Kerr effect in a weak electric field allows one to define experimentally the product of the dipole moment and optical anisotropy. The Kerr effect in a strong electrical field can be used to obtain these two characteristics independently.[27, 28]

The piezoelectric effect of organic thin film is also studied. Piezoelectric materials form the basis of a wide variety of electromechanical devices. The piezoelectric effect lies in the microscopic structural symmetry of crystalline unite cells. Up to 1960s, all piezoelectric devices made used either a single crystal structures such as quartz or polycrystalline ceramics such as lead titanate zirconate perovskites in which the dipole moments of individual crystalline units could be oriented by an applied electrical field. In 1969, Kawai discovered that strong piezoelectric effects could be induced in poly (vinylidene fluoride) (PVDF) by application of an electric field.[29] Due to the great potential of a completely flexible piezoelectric material that can be inexpensively

fabricated into thin films, a wide variety of devices has been fabricated and developed.[29] These include: audio frequency transducers, such as microphone and headphones having excellent frequency response and low distortion because of the low density light weight transducer film; ultrasonic transducers for underwater applications such as hydrophones and medical imaging applications; electromechanical transducers for computer and telephone keypads and a variety of other contactless switching applications. The commercial devices based on ferroelectric polymers have been limited by reproducible and uniform properties and thermal stability.[29] Such processing complexities required several years to develop PVDF film into commercial applications. Research has been done to improve the dielectric, piezoelectric properties by modification of the chemical structure of the polymer, such as synthesizing copolymer Vinylidene fluoride with trifluoroethylene (TrFE) or tetrafluoroethylene (TFE).[30] Piezoelectric activity has been observed in a wide variety of other polymers such as a completely amorphous alternating copolymer of vinylidene cyanide and vinyl acetate,[31] Nylons such as Nylon 11 and Nylon 9, cyanopolymers such as polyacrylonitriles and poly (vinylidene cyanide)s, polyureas such as aromatic polyureas and aliphatic polyureas, polythioureas and some biopolymers such as wood cellulose, cellulose derivatives, chitin, amylose, bone and collagen, keratin, and various proteins and DNA and some optical active polymers such as polypropylene oxide(PPO), poly-β-hydroxy butyrate, and poly-lactic acid.[32]

Piezoelectric and pyroelectric polymers are usually poled under DC field around T_g with different length of time varying from seconds to hours. Dynamic electrical field poling for piezoelectric polymers are less reported. However piezoelectric polymer dynamic properties are very import for their applications as electromechanical sensors. The properties of several piezoelectric and pyroelectric polymers are compared Table 1.1.

Table 1.1 Comparison of dynamic piezoelectric and pyroelectric properties of polymers

Polymers	Electrical frequency	Electric field strength	Significant properties	Reference
Polyvinylidene Fluoride (PVDF)	0.003-408 Hz (25^0C)	100kV/cm-2.5MV/cm	Excellent resistance to creep, fatigue and chemical attack, high mechanical and impact strength, large piezoelectric effects after poling	[33]
Aliphatic polythioureas	10Hz (55^0C)	500kV/cm	Large reversible pyroelectric constant after poling. Pyroelectric constant is stable at high temperature 120^0C.	[32]
N-phenylated aromatic polyurea	0.01Hz (120^0C)	0.5-1.5MV/cm	Easy process in colorless, transparent and flexible thin films that exhibit large second-order optical nonlinearity and transparency in UV region.	[32]
Poly(vinylidene Cyanide and Vinyl Acetate) copolymer P(VDCN/VAC)	0.00013Hz (-100^0C-150^0C)	50-200kV/cm	Very effective control of copolymer molecular orientation by introducing large dipole moments cyanide group into vinylidene polymer molecules	[34]
Nylon 9	80Hz (-70^0C-80^0C)	200-800kV/cm	Odd nylon can have a spontaneous polarization in the unit cell of the crystalline phase and thus are good piezoelectric materials.	[35]
Nylon 77	0.017Hz (25^0C)	0.5-2.5MV	Same as nylon 9	[32]
Poly-γ-methylglutamate (PMLG)	20Hz (-170^0C-170^0C)	—	Synthetic polypeptides with piezoelectric effects	[36]
Poly-γ-benzyl-L-glutamate (PBLG)	156Hz, 1.9kHz, 2.5kHz, 5kHz, 10kHz (25^0C)	2MV/cm	Ultra-thin biopolymer PBLG can be grafted onto a substrate and shows large piezoelectric effects	[37]
PPO	3kHz-83kHz (25^0C)	118-220kV/cm	Fast response to electric field	Our research

A variety of experimental techniques have been used to obtain both absolute and relative change of the second order harmonics generation. Typical Mach-Zehnder interferometry is used for measuring second harmonics generation for poled polymers. There are many techniques that are currently used to measure electrooptic effect. Hayden used Mach-Zehnder interferometric technique for measuring the birefringence.[38] Jungbauer also reported using Mach-Zehnder interferometry to measure the eletrooptical coefficient of poled linear epoxy polymers with tolane chromophores.[39] Winkelhahn has reported a Normaski interferometry technique to measure the piezoelectric and electrorestrictive properties of poled-polymer guest-host system consisting of a polycarbonate host and 4-dimethylamino-4'-nitrostilbene dye. They can also determine the frozen polarization from the ratio between piezoelectric and electrorestriction constants of the electret film.[40] T. Jaworek also applied optical Normaski interferometer to measure the thickness change of 15nm thick monomolecular film of polymer-γ-benzy-L-glutamate induced by electric field.[41] Winkelhahn et al. have shown that this setup is capable of detecting periodic thickness changes with subpicometer resolution at modulation frequencies between 10Hz and 100kHz.[40, 42] Han introduced a single beam polarization interferometry method to measure the Pockels coefficients in a $Bi_{12}SiO_{20}$ single crystal.[43] Uchiki and Kobyashi have described a Fabry-Perot interferometric technique to measure birefringence. In this approach, the light beam is perpendicular to the film. Scanning the wavelength generates interference patterns related to the film thickness and refractive index.[44] Teng and Man used an elliposometric technique to measure the birefringence. A thin film sample is prepared with one surface coated with a reflective gold layer. The opposing surface is illuminated by a laser beam incident at an angle of 45^0 to the surface. The phase difference between the s- and p- polarized reflected beam is measured with a Soliel-Babinet compensator. Variations of this difference at the frequency of an applied electric filed are measured.[45] An attunated total reflection (ATR) technique has been described that can measure both components of electrooptic coefficient as well as piezoelectric contribution.[46]

Although the properties of a bulk material are well characterized, thin film behavior is expected to be substantially different. One reason is that thin film properties are strongly influenced by interfacial properties. The thin film has a substantially higher

surface-to-volume ratio than does a bulk material. Therefore, the study of the optical, electrical and chemical properties of thin film material is of increasing importance in opto- and microelectronics.

It is well known that the structure and processing of thin films play a vital role in determining the film properties. The understanding of film/substrate interaction and thin film interfacial mobility under external forcing field is limited. These effects could be important to the integrity and performance of electronic devices. Especially as the miniaturization with high-speed devices continues, the desired thickness of such inter-connect dielectric film reduces concomitantly making interfacial effect significant. It is very important to quantitatively study the effect of geometric confinement such as thickness and electrical field. Research has shown that thin organic films undergo catastrophic breakdown when stressed by high electric fields and not all organic films of the same thickness undergo breakdown at the same electrical strength. Therefore, it is necessary to study polymer chain dynamics under electric field to improve the reproducibility and reliability of microelectronic devices.

1.3 A Brief Introduction to Interferometry

Heterodyne interferometry is a non-destructive technique for measuring the thickness change of thin films. The film thickness is determined by measuring the phase difference of the interference of reference beam and sample beam. The technique is capable of monitoring in real time the thickness and refractive index change of thin films due to external stimuli. The high resolution (about 0.05nm) provides small relative changes of refractive index as film is subjected to a stimulus. The focus of this research is to study quantitatively the effect of geometric confinement (i.e. thickness), interfacial effects, and electrical field on the PPO polymer chain dynamics. This thesis presents the results of PPO thin film, where both linear and second order harmonics generation signal at high frequency electric field is observed. In this study, the experimental techniques simultaneously measure the film refractive index change and thickness change under electric field independently to obtain the changes in film thickness and chain orientation as a function of electrical field strength and frequency. The measurement elucidates the polymer chain dynamics.

Chapter 2 Interferometry

Interferometry is based upon comparing the difference in optical path length integrated along a ray in the film to the optical path along a reference path or to an absolute value of phase. The optical path length change may occur due to changes in refractive index and/or film thickness. The measurement probes displacement, deformation, shape and surface characterizatics such as roughness.[2] It can also provide information about density fluctuation, temperature and the Young's modulus of thin film. As a nondestructive diagnostic technique, laser interferometry has been utilized in silicon processing thin film thickness, etching, and deposition monitor and control.[2]

Modern laser Interferometry covers a variety of optical and optoelectronic techniques based on optical interference.[48] In general, it is a complex opto-electronic measuring system that includes a laser, an optical unit, a photoelectric transducer, electronics, and software tools. Modern laser interferometers can measure linear displacements, speed, acceleration, vibration parameters, smoothness, angles of rotation, and indices of refraction. In this work, we study the polymer chain dynamics. We can demonstrate the great advantage of heterodyne interferometry in this measurement by comparing with other current available interferometry methods.

In order to achieve interference between two coherent beams of light, an interferometer divides the initial beam into two or more parts that travel diverse optical paths and then reunite to produce an interference pattern. One criterion for classifying interferometers distinguishes the manner in which the initial beam is separated. Two methods are commonly used to obtain two beams from a single source. Wavefront division and Amplitude division.[50] Wavefront division uses apertures to isolate from separated portions of the primary wavefront. British scientist Thomas Young (1773-1829) first investigated the interference between the waves generated by two pinholes illuminated by a weak light source.[48] Young's double slit is one case of wavefront division. Amplitude-division interferometers instead use some type of beam splitter that divides the initial beam into two beams. Michelson interferometer is one of the examples of amplitude division interferometer. Michelson interferometry, first introduced by

Albert Michelson in 1881 has played a very important role in modern physics. Figure 2.1 shows the schematic of Michelson interferometer.

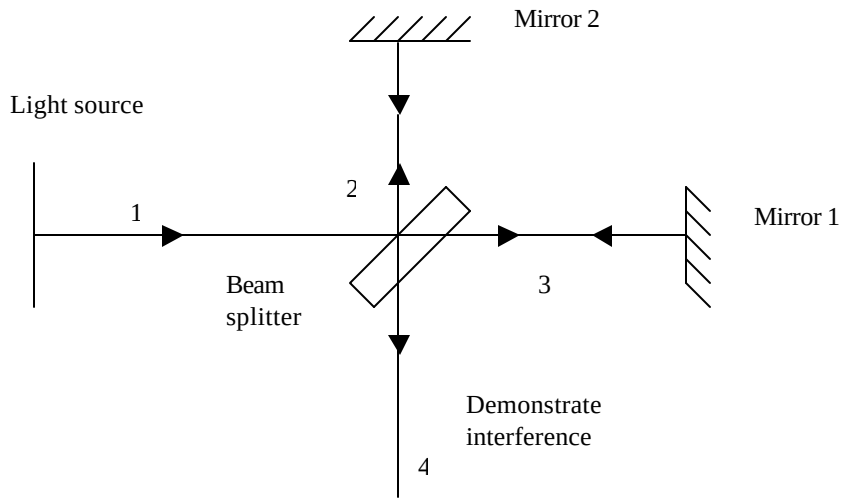

Figure 2.1 Schematic of Michelson interferometer

One of the mirrors is movable along the direction of the beam by means of an accurate trace and micrometer screw. In this way, the distance between the optical path 2 and 3 can be gradually varied and therefore Michelson interferometer is easily adaptable to the measurement of thin films, and also adaptable to the determination of the refraction index of gases. But the resolution is limited by signal to noise ratio coming from low frequency noise.

The other means of classification distinguishes interferometry by the interference of two beams or multiple beams. Michelson interferometer is one case of two beams interference, whereas, Fabry-Perot interferometer operates with multiple beams. Fabry-Perot interferometer makes use of plane parallel plate to produce an interference pattern by the multiple beams of transmitted light. Figure 2.2 shows the schematic of a Fabry-Perot interferometer.

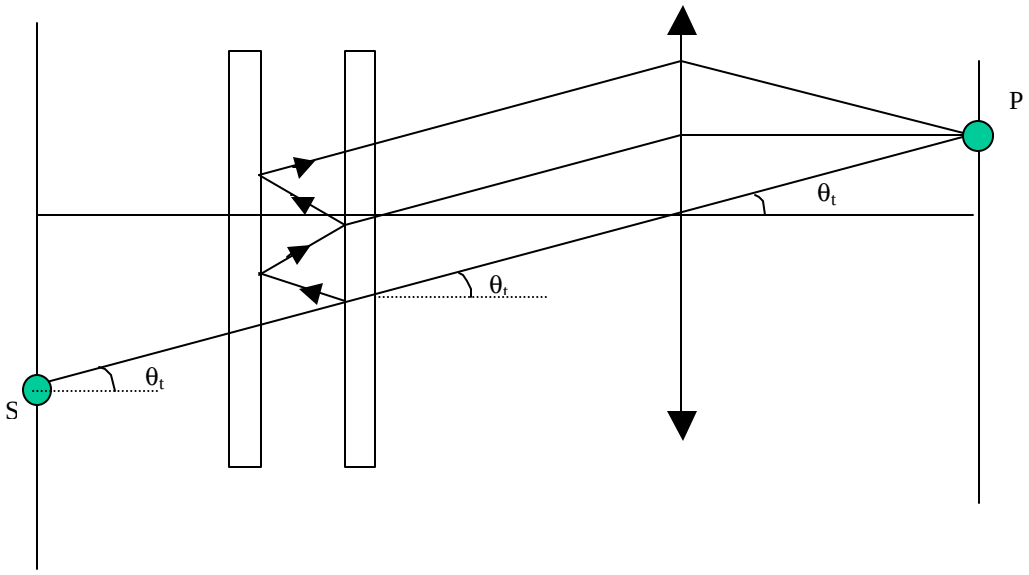

Figure 2.2 Fabry-Perot interferometer

Fabry-Perot interferometry can be used for precise wavelength measurements, analysis of hyperfine spectral line structure, determination of refractive indices of gases, and the calibration of the standard meter in terms of wavelengths.[50] As for the thin film thickness changes, it is not as sensitive as differential interferometry.[47]

Michelson, Van Cittert, Zernike and Wolf also contributed to the statistical characteristics of light sources and their role in shaping the interference pattern. Basov, Prokhorov, and Townes were awarded the Nobel price for their original contribution to the foundation of laser interferometry applied to quantum electronics.[48] The advent of lasers (i.e., high temporal and spatial coherent sources) makes photoelectric detection and the introduction of light modulation possible. This invention not only increases the sensitivity by several orders of magnitude, but also makes dynamic measurement possible due to low time lag photo-detectors. The invention of new kinds of interferometry, such as homodyne, heterodyne, holographic, Doppler, and Speckle interferometers also rely on the laser source.

Heterodyne interferometry techniques involve the use of two beams split from the same laser. The reference beam has its phase shifted by a specified amount. The phase difference between the reference beam and the measuring beam varies in a linear manner

and results from the changes in the optical path of the measuring beam. The two beams of different phases interfere and yield an optical signal picked up by a photodetector that delivers electric signal to a phase meter that measures the phase difference. The heterodyne interferometer diminishes the role of low frequency noise and hence, improves signal-to-noise ratio. This method provides an opportunity to detect more accurately fringes, simplify optical systems, and extend the capabilities of interferometers.[48] In view of the quantum nature of lasers, radiation and the random character of emission of photoelectrons, the photocurrent contains a fluctuating component (shot noise).

The present-day heterodyne interferometers employ external modulation based on Doppler, Bragg, and Pockels effects.[49] The Doppler diffraction modulator operates on the principle of diffraction of the laser beam by a moving grating of the amplitude or phase type. The diffraction grating can be viewed as a transparency with the transmission which periodically changes along one of the coordinates. The power of the diffracted beam is proportional to the square of the depth of the transmission modulation. Therefore, the diffraction grating acts as both a frequency modulator and also a beam splitter.

An acousto-optic modulator creates a dynamic ultrasound wave that diffracts the laser beam similar to that achieved by a moving amplitude grating. The medium traversed by the ultrasonic wave acts as a moving phase grating since the wave periodically changes the density of the medium, and therefore varies the its refractive index. There are two types of acousto-optic modulators. The Raman-Nath modulator works at relatively low frequencies in the range of 1-10MHz and a short interaction length. Whereas Bragg modulator works at higher frequencies and within a longer interaction length whenever the incident laser beam strikes the acoustic column at a Bragg angle.[1]

Classical interferometers produce a stationary interference pattern by superimposing two coherent beams. Switching interferometers produce a nonstationary interference pattern because one of the beams undergoes phase modulation. Laser-

[1] $\theta_B=\arcsin(\lambda/2\Lambda_a)$, λ is the wave length of the incident laser beam, Λ_a is the wavelength of the acoustic wave moving in the medium.

Doppler anemometers intended to measure flow velocities, the interference pattern results from the interference of two coherent beams, one of which is scattered by moving particles. Due to the Doppler effect (The movement of a wave source can affect the observed frequency), the frequency of the scattered beam differs from that of the probing beam resulting the nonstationary interference pattern. Laser-Doppler interferometer is used to measure the velocities of both liquid and gas flow.

Holographic interferometry was invented between 1965-1966. The principle of holographic interferometry is that illuminating a hologram with the coherent light beam reconstructs the image of an object.[50] If it is possible to obtain two or more similar wave representative of the object images at different moments of time, these waves will interfere and produce the fringe pattern which can provide information on the varying object. In comparison with the methods of classical interferometry, holographic interferometry offers a number of enhancements: holographic plate can record the waves from a scattered object at different time, image recording can be made at different wavelength, If the object surface structure is invariable, it has no effect on the interference pattern that reproduces the changes in the objects and therefore it is suitable for transparent and diffuse objects. Holographic interferometry can also provide the opportunities of observing the interference pattern of laser propagating in different directions and thus obtain a large amount of information on the distribution and changes of optical inhomogeneities in the object. Implementation of holographic interferometry is complicated. The first challenge has to do with a low sensitivity of the high-resolution holographic recording materials. The second difficulty lies in the stringent requirements imposed upon the time and space coherence of light sources. The third and also the main difficulty relates to the conflicting requirements on the localization of interference fringes. On the one hand, the localization of fringes is actually unavailable at a high coherence of the laser source. On the other hand, a decrease in the degree of coherence due to the diffuse scattering of the light by the object and to object deformation limits the fringe localization region that may not coincide with the object surface. In general, holographic interferometry can analyze changes in the structure of transparent objects such as plasma or glass, plastic and crystalline elements, and to investigate the object

deformations or vibrations and to study the time variation of the light field from the an object.

When an object with a diffuse surface is illuminated by coherent light or its image is formed with the aid of an optical system, a pattern of small light and dark spots or speckles appears. Speckle interferometry utilizes this phenomenon to measure displacements, deformations, and rotations of diffuse objects or their parts. Compared with others interferometry methods, speckle interferometry has such advantages: a simple optical system tolerant to the stability and vibration-resistance of the installations, simplicity of analyzing experimental data, and adjustable sensitivity.

From the above discussion, we can see that for changes in thin film, heterodyne interferometer is a suitable probe that is nondestructive, reasonably simple and accurate.

References:

[1] D. Gupta, Paul S. Ho, Diffusion Phenomena in Thin Films and Microelectronic Materials, Noyes Publications, NJ, (1988).

[2] Irving P. Herman, Optical Diagnostics for Thin Film Processing, Academic Press, (1996).

[3] Stanley Wolf, Silicon Processing for the VLSI ERA volume 3, Lattice Press, Sunset Beach, CA, (1994).

[4]Stanley Wolf, Richard N. Tauber, Silicon processing for the VLSI ERA, Volume 1: Process technology, 2nd edition, Lattice Press, Sunset Beach, CA, (1999).

[5] D.M. Burland, R. D. Miller, C. A. Walsh, Chem. Rev., Vol. 94, 31-75 (1994).

[6] S.M. Marder, R. Kippelen, N. Peyghambarian, Nature, Vol. 388, No. 6645, 845-851, (1997).

[7] G. A. Lindsay, K. D. Singer, Polymers for Second-Order Nonlinear Optics, American Chemical Society, Washington, D.C., (1995).

[8]A. Chen, V. Chuyanov, S. Garner, H. Zhang, W.H. Steier, Opt. Lett., Vol. 23, No. 6, 478-480, (1998).

[9] J. P. Rabe,; W. K. Knoll, Opt. Commun. Vol. 57, No. 3, 189-192, (1986).

[10] B. Rothenhausler, C. Duschel,, W. Knoll, Thin Solid Films, Vol. 159, 323-330, (1988).

[11] Abraham Ulman, An Introduction ot UltraThin Organic Films from Langmuir-Blodgett to Self – Assemblely, Academic Press, Inc. ,(1991).

[12] D. S. Chemla and J. Zyss, Nonlinear Optical Properties of Organic Molecules and Crystals, Academic Press, New York, (1987).

[13] S.R. Marder, J.E. Sohn and G. D. Stucky, Materials for nonlinear optics: chemical perspectives, Am. Chem. Soc. Symp. Ser. 455, (1991).

[14] J. Zyss, Molecular Nonlinear Optics, Academic Press, New York, (1994).

[15] J. W. Wu, J. F. Valley, S. Ermer, et. al, Appl. Phys. Lett., Vol. 58, No. 3, 225-227, (1991).

[16] S. Bauer, W. Ren, S. Yilmaz, et. al. Appl. Phys. Lett., Vol. 63, No. 5, 2018-2020, (1993).

[17] S. Aramaki, Y. Okamoto and T. Murayama, Japanes J. Appl. Phys. Vol. 33, No. 10, 5759-5765, (1994).

[18] G. Meredith; J. Vandusen, D. Williams, Macromolecules, Vol. 15, No. 5, 1385-1389, (1982).

[19] K. Singer, J. Sohn, S. Lalama, Appl. Phys. Lett. Vol. 53, No. 19, 1800-1802, (1988).

[20] J. Hill, P. Pantelis, G. J. Davies, Electron Lett., Vol. 23, No. 13, 700-701, (1987).

[21] M. Eich, H. Looser, D. Yoon, R. Twieg, G. Bjorklund, J. Opt. Soc. Am. B , Vol. 6, No. 8, 1590-1597, (1989).

[22] A. Knoesen, N. Molau, D. Yankelevich, M. Mortazavi, A. Dienes, Int. J. Nonlinear Opt. Phys. Vol. 1, 73, (1992).

[23] S. Tasaka, O. Furutani, N. Inagaki, Materials Research symp.-proceedings. V.6000, 107-115, Materials research society, Warrendale, PA, USA, (2000).

[24]C. R. Paresh, K. D. Puspendu, European Polymer Journal, Vol. 32 No. 1, 51-55, (1996).

[25]M. V. Volkenshtein, Configurational Statistics of Polymer chains, Wiley-Interscience , New York, (1963).

[26] V. N. Tsvetkov, Rigid-Chain polymers. Hydrodynamic and optical properties in solution, Consultants Bureau, New York, (1989).

[27] S. V. Lyulin, I. M. Neelov, Y. Y. Gotlib, Macromolecules, Vol. 31, 9354-9361, (1998).

[28] A. V. Lezov, T. A. Rotinyan, E. I. Rjumtsev, Opt. Spectrosc. Vol. 76, 1008-1012, (1994).

[29] H. S. Halwa, Ferroelectric Polymers Chemis try, Physics, and Applications, Marcel Dekker, Inc. , (1995).

[30] A. J.Lovinger, G. T. Davis, T. Furukawa and M. G. Broadhurst, Macromolecules Vol. 15, No. 2, 323-328, (1982).

[31] M. Miyata, S. Yoshikawa, M. Ko, Polym. J. Vol. 12, No. 12, 857-860, (1980).

[32] H. S. Nalwa, Ferroelectric polymers chemistry, physics, and applications, Marcel Dekker Inc., (1995)

[33] J. C. Hicks, T. E. Jones, Ferroelectrics, Vol. 32, No. 1-4, 119-126, (1981).

[34] S. Miyata, M. Yoskhikawa, S. Tasaka, and M. Ko, Polymer J. Vol. 12, No. 12, 857-860, (1980).

[35] G. Wu, O. Yano, and T. Soen, Polymer J. Vol. 18, No.1, 51-61, (1986).

[36] M. Date, S. Takashita, E. Fukada, J. Polymer Sci. A-2, Vol. 8, 61-70, (1970).

[37] T. Jaworek, D. Neher, G. Wegener, R. H. Wieringa, A. J. Schouten, Science, Vol. 279, 57-62, (1998).

[38] M. Sigelle, R. J. Heirle, Appl. Phys. Vol. 5, 4199-4203, (1981).

[39] D. Jungbauer, J. Teraoka, D. Y. Yoon, B. Reck, J. D. Swalen, R. Twieg, and C. G. Willson, J. Appl. Phys. Vol. 69, No. 12, 8011-8017, (1991).

[40] H. J. Winkelhahn, H. H. Winder, D. Neher, Appl. Phys. Lett. Vol. 64, No.11, 1347-1349, (1994).

[41] T. Jaworek, D. Neher, G. Wegner, R. H. Wieringa, A. J. Schouten, Science, Vol. 279, 57-62, (1998).

[42] H. J. Windkelhahn, T. Pakula, D. Neher, Macromolecules Vol. 29, No. 21, 6865-6871, (1996).

[43] S. H. Han, J. W. Wu, J. Opt. Soc. Am. B. Vol. 17, No. 7, 1205-1210, (2000).

[44] H. Uchiki, T. J. Kobayashi, J. Appl. Phys. Vol. 64, No. 5, 2625-2629, (1988).

[45] Teng, C.;Man, H.;Appl. Phys. Lett. Vol. 56, No. 18, 1734-1736, (1990).

[46] M. Dumont, Y. Levy, D. Morichere, Inorganic Molecules for Nonlinear Optics and Photonics, Kluwer Pub. (1991).

[47]Frank L. Pedrotti, S. J., Leno S. Pedrotti, Introduction to Optics, Prentice-Hall Inc. (1987).

[48] A. Ya Karasik, B. S. Rinkevichius, V. A. Zubov, Laser Interferometry Principles, CRC Press. (1999).

[49] Zubov, V. A., Sultanov, T. T. J. Soviet Laser Research, Vol. 13 No. 2, 140-151, (1992).

[50] P. Hariharan, Basics of Interferometry, Published by Academic Press, Inc., San Diego, CA (1992).