Abstract

In the proposed research various holographic optical elements (HOEs) have been studied to form different class of optical interferometers and also their use has been exploited to enhance anticounterfeiting ability of security holograms. This work is presented in the thesis entitled ‘Investigation and implementation of holographic optical elements in optical interferometers and in security holograms’. The thesis contains a number of new techniques of HOE based interferometers utilizing minimal optics. Different HOEs based simple, compact and robust two-beam and one-beam interferometers have been constructed and analyzed, which are quite suitable for performing optical test studies. A theory for these holographic interferometers has been developed and applied to study of phase objects. A holographic optical element based two-channel interferometer, which is suitable for performing optical test studies of two different phase (transparent) phase objects simultaneously and independently, has also been proposed. This interferometer has utility for comparative test studies between two different phase objects in real time. Holographic optical element based interferometer that can study a single object in two different modes (i.e. infinite and finite fringe mode) at the same time has also been developed. For quantitative measurements phase stepping in these holographic interferometers has also been demonstrated. The repositioning of HOEs in these interferometers is essential. Studies on the effect of HOE misalignments and aberrations on interferograms have been carried out. Further the applications of HOEs have been investigated to enhance the anticounterfeit-ability of security holograms. HOEs have attractive features such as multiplex capability to perform multiple simultaneous functions (e.g. focusing, beam splitting, and spectral filtering, all in the same area of the HOE) and potential ease of mass production through replication. Investigations have been made for incorporation of different kinds of HOEs in security holograms to serve variable, hidden and encoded features/information, which ascertain the holograms validity. Various configurations, where HOEs are used to angularly encode and decode security features in the security holograms, have also been discussed. The security holograms whose construction and reconstruction are based on particularity of extended fractional Fourier transform in addition with angular and special encoding through HOE has also been investigated. Different techniques based on moiré, holographic interferometry and
generalized Fourier transform have developed and presented. The entire work in this thesis is organized in seven chapters:

The first chapter contains a general introduction of holographic optical elements (HOEs) which have been formed by two or more interfering beam of coherent light and can function as gratings, lenses, and aspheric or any other type of optical element. The properties of HOEs with their designing concept and recording materials have also been discussed. An overview of research and development in the area of HOE based interferometers and in security hologram has also been given. The concise introduction of the various HOEs used in our interferometers and in security holograms has also been presented.

The second chapter deals with holographic optical elements (HOE) based two beam interferometers. The HOE based two beams interferometer as available in literature, consists large number of holographic optical elements. The generation of multiple and compatible HOEs in turn involves employment of a large number of precision optical components and their related alignment procedures. Further, sometimes the repositioning of the generated multiple HOEs for realization of the holographic optics based interferometer is quite critical, complex and time-consuming. During this research work, various modified HOE based two beam interferometers utilizing minimal optics, which overcome the difficulties in the earlier methods, have been constructed. These interferometers are quite suitable for studying phase objects. These holographic optical elements (HOEs) based interferometers allow simplification of the optical arrangements with improved functionality and also eliminate the aberrations of the optical system under certain conditions. Detail investigation on these interferometers is discussed in this chapter.

The third chapter deals with application of HOEs in one-beam interferometer where two arms of the interferometers are located in a single collimated beam. Since both arms are part of the same beam and fewer optical components are involved, these interferometers are robust and compact. These interferometers are more suitable for the industrial environment as the same effects are present in both arms making them insensitive to external disturbances. Two different schemes of HOE interferometers have been described in this chapter. In the first scheme two
arms are attached with each other whereas in the second configuration the two beams are derived from the same collimating optics but are slightly spatially separated. The fabrication processes of HOEs and experimental procedures for both interferometers have been discussed.

In the fourth chapter a holographic optical elements based two-channel interferometer has been discussed which is suitable for performing optical test studies on two different phase objects simultaneously and independently. This interferometer has utility for comparative test studies between two different phase objects in real time and can also be used to study phase objects independently. The issue of repositioning of HOEs is very critical. A slight misalignment in a HOE would result in finite fringe interferograms in the observation plane. A detail study has been made to analyse lateral and rotational misalignment in HOEs and its effect on resulting interferometric information.

In the fifth chapter a holographic optical elements based interferometer has been presented in which two different phase objects can be studied simultaneously and independently and also the same interferometer can study a single object in two different modes i.e. finite fringe and infinite fringe mode at the same time. The optical configuration of the proposed interferometer is such that it utilizes only two optical components: a compound holographic optical element (HOE) and a diffraction grating. Without using any external phase shifting device, simultaneous phase shifting is possible in this configuration by only moving a single inbuilt element. Theoretical as well as experimental analysis carried out with HOE based interferometers for the testing of phase objects, measurement of refractive indices of transparent objects and measurement of wedge angle are also presented.

Hologram is one of the most reliable means for authenticity identification of official papers, plastic cards etc. However, the duplication possibility of hologram themselves is rising because of recent rapid technological advances. Different configurations of HOE encoded security holograms are discussed in the sixth chapter. In these security holograms, HOEs are used as key hologram to angularly encode and decode the verifiable security features. Holographic optical elements based moiré pattern encoding in addition to extended fractional Fourier transform has been suggested in this chapter. In the extended fractional Fourier
transform hologram (EFRTH), different planes (input/output plane and hologram recording/reconstruction plane) are situated at a pre-determined concealed asymmetric location on two sides of constructing and reconstructing lenses. To further enhance the security measures multiple objects attached with separate periodic patterns were used and thus giving another level of security through formation of moiré pattern. For correct retrieval of the desired moiré images one need to specify the all concealed extended fractional Fourier transform parameters in addition to the key hologram and respective decoding patterns. Because the hologram contains too many parameters, which are impossible to guess, the proposed hologram could be considered as a high security hologram. These types of holograms can also be used as security codes for better protection against counterfeiting in the embossed holograms.

In many of security hologram encoding schemes diffuser key have been used. Though it enhance the anticounterfeit ability of security hologram but diffuse key produces highly distorted wavefront demanding critical alignment of security hologram in reading process. To overcome this problem dual reference beam encoding has been exploited in the seventh chapter. Two reference beams holography is a well known phenomenon used in high resolution holographic interferometry for nondestructive testing where two images has its own reconstruction beams, one has access to each image separately, as well as to their mutual interference pattern. This technique is advantageous over diffuser based approaches in terms of easy alignment and repositioning of security hologram and also it brings an improvement in the security level of the verification systems. Further to maximize the security potential of the hologram this technique has been applied with extended fractional Fourier transform. These types of security holograms are quite suitable for machine and/or visual inspection and possess high degree of anti-counterfeit ability and in addition do not require expensive reading machines.