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Optical interferometers and their application in scientific research

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ABSTRACT

Optical Interferometers and Their Application in Scientific Research: The research group for application in molecular, biomedical and material science at ELI Beamlines needs to control the delay of synchronized laser beams down to femtosecond precision. The aim of this student project was to apply interferometry in femtosecond delay line stage tests for atomic, molecular, and optical sciences and for coherent diffractive imaging. For this purpose, a Michelson Interferometer was built using ELI in-house resources. Using a bam splitter, a laser beam was split into two arms and then recollected to create an interference pattern. This pattern was detected by a fast 2GHz Thorlabs photodiode, DET025A/M, with à 400-1000 nm sensitivity range and rise/fall times of 150 ps, in order to calibrate a femtosecond delay line stage. The Aerotech PRO190SL/ SLE was used as the translation linear stage. This stage served as the main component of the delay line tests. Further, Attocube sensors based on the Fabry-Perot Interferometer technique were added to the set-up to improve the precision and reliability of the calibration method. The advantages, disadvantages and limits of this method as well as lessons learned will be discussed from both an educational and scientific point of view.

Key words: Optical Interferometers, Material science, Optical sciences

INTRODUCTION

Optical techniques are extensively used for high precision diagnostics and process monitoring in physical, biological, and engineering sciences. Interferometry falls in one such class of diagnostics. It relies on changes in the refractive index in the medium arising from variations in the material density. The physical region in which imaging is being carried out is required to be transparent. The light source best suited for an interferometer is a laser. Owing to its features such as greater accuracy, resolution, instantaneous response and non-intrusive nature, interferometry proves to be advantageous and extensively utilized in broad spectrum of applications. The present chapter deals with the description of laser interferometers in visualization and monitoring of processes involving fluid flow, heat transfer, and mass transfer. The chapter is divided into two sections. In the first section, we discuss the basic principles of interference and fringe formation. It includes the principles and operations of various interferometer configurations such as Michelson, Mach-Zehnder, holography, phase shifting, speckle, schlieren and dual wavelength interferometry. Interferometers can provide vivid images of temperature and solutal concentration fields. Their real utility is in the quantitative determination of transport properties in addition to heat and mass fluxes. The second section describes the applications of interferometry in studying transient heat conduction, buoyancy-driven convection in a rectangular cavity and superposed fluid layers, and crystal growth from an aqueous solution. These illustrate the utility of interferometry in engineering and research.

According to the general relativity, gravitational waves (GW) are produced when the curvature of spacetime disturbed by accelerating mass. The ripples in the curvature of spacetime propagate at the speed of light. A GW causes a tiny time dependent quadruple change of strain in the plane transverse to the wave's propagation direction. The space is stretched in one direction while is shrunk along its perpendicular direction. The strength of GW 'h' is expressed by the dimensionless strain. Due to the quadruple nature of Michelson interferometer, it is suitable device for gravitational wave detection. The interference pattern is linear measure of the strain. The amplitudes of GWs radiated from astrophysical sources at Earth are typically of the order of など貸態怠 or smaller. Detection of such weak strains needs high sensitive devices. For increasing the sensitivity of the interferometer, the lengths of the interferometer arms were increased to the order of kilometers and multi-path cell or Fabry-Perot optical cavity was used in each arm. So the light can be stored for a time comparable to the time scale of GW signal. Long base line gravitational wave detectors such as LIGO, VIRGO, GEO and TAMA are now operational. In the presence of GW, the change in the length of arms is very small. Hence many noises such as seismic noise, thermal noise and quantum noise limit the sensitivity of interferometer. Quantum noise is the fundamental and unavoidable noise in new generation of these interferometers and is due to the light-interferometer interaction. So the sensitivity of laser GW detector depends on the quantum state of light. It was shown that depending on the parameters of interferometer such as arm's lengths, frequency of laser and mass of mirrors, the optimum quantum state for the dark port is vacuum squeezed state with specific squeezing factor. By employing this optimum quantum state in the dark port, the quantum noise and optimum laser power reduce one order of magnitude relative to the conventional interferometers

In Michelson and Mach-Zehnder interferometer techniques, the reference and measurement beams travel along different paths and so these techniques are sensitive to vibrations. For in-situ measurements, Michelson, M-Z, optical and heterodyne techniques are desirable. Of these, the last one is the most sensitive technique. For assessment or surface topography, phase shifting interferometry and dynamic interferometry techniques are suitable, which have sub nanometer sensitivity and are suitable for very fast assessment of large surfaces. These techniques have sub nanometer sensitivity in depth profile measurement and micron or better in spatial resolution. For laser heating or cooling studies of solids optical heterodyne, Michelson and Mach-Zehnder interferometer are suitable. Of these, only optical heterodyne technique can reveal temperature changes of mK, in real time. Dynamic interferometry technique is not suitable for real time measurements of temperature changes induced by a laser beam along the beam path. When the temperature or length changes are large and if one is interested in average changes over a long period of time then Michelson, Mach-Zehnder and heterodyne techniques are equally good. When the changes in temperature are small, optical heterodyne technique is superior to other techniques. If one is interested in absolute temperature measurement then rare-earth luminescence or spectral measurements are better.

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