1 Introduction

Dennis Gabor invented holography in 1948 as a method for recording and reconstructing amplitude and phase of a wave field [37, 38, 39]. He created the word *holography* from the Greek words 'holos' meaning whole or entire and 'graphein' meaning to write.

A holographically stored image or hologram is the photographically or otherwise recorded interference pattern between a wave field scattered from the object and a coherent background named reference wave. It is usually recorded on a flat surface, but contains the information about the entire three-dimensional wave field. This information is coded in form of interference stripes, usually not visible for the human eye due to the high spatial frequencies. The object wave can be reconstructed by illuminating the hologram with the reference wave again. This reconstructed wave is by passive means indistinguishable from the original object wave. An observer recognizes a three-dimensional image with all effects of perspective and depth of focus.

Gabor illuminated in his original set-up the hologram by a parallel beam through the mostly transparent object. Therefore the axes of both the object wave and the reference wave were parallel. The reconstruction of this hologram results in the real image superimposed by the undiffracted part of the reconstruction wave and the so called ‘twin image’ (or virtual image) laying on the optical axis, i.e. in-line. Significant improvements of this in-line holography were made by Leith and Upatnieks, who introduced an off-axis reference wave [91, 92]. Their set-up separates the two images and the reconstruction wave spatially.

One major application of holography is Holographic Interferometry (HI), developed in the late sixties of the last century by Stetson, Powell [127, 151] and others. HI made it possible to map the displacements of rough surfaces with an accuracy of a fraction of a micrometer. It also enabled interferometric comparisons of stored wave fronts existing at different times.

The development of computer technology allowed to transfer either the recording process or the reconstruction process into the computer. The first approach led to *Computer Generated Holography* (CGH), which generates artificial holograms by numerical methods. Afterwards these computer generated holograms are reconstructed optically. This technique is not considered here, the interested reader is referred to the literature, see e.g. Lee [90], Bryngdahl and Wyrowski [11] or Schreier [140].

Numerical hologram reconstruction was initiated by Goodman and Lawrence [42] and by Yaroslavskii, Merzlyakov and Kronrod [81]. They sampled optically enlarged parts of in-line and Fourier holograms recorded on a photographic plate.

These digitized conventional' holograms were reconstructed numerically. Onural and Scott improved the reconstruction algorithm and applied this method for particle measurement [106, 93, 105]. Haddad et al. described a holographic microscope based on numerical reconstruction of Fourier holograms [46].

A big step forward was the development of direct recording of Fresnel holograms with Charged Coupled Devices (CCD's) by Schnars and Jüptner [130, 131]. This method enables now full digital recording and processing of holograms, without any photographic recording as intermediate step. The name which has been originally proposed for this technique was 'direct holography' [130], emphasizing the direct way from optical recording to numerical processing. Later on the term **Digital Holography** has been accepted in the optical metrology community for this method. Although this name is sometimes also used for Computer Generated Holography, Digital Holography is used within the scope of this book as a designation for digital recording and numerical reconstruction of holograms.

Schnars and Jüptner applied Digital Holography to interferometry and demonstrated that digital hologram reconstruction offers much more possibilities than conventional (optical) processing: The phases of the stored light waves can be calculated directly from the digital holograms, without generating phase shifted interferograms [128, 129]. Other methods of optical metrology, such as shearography or speckle photography, can be derived numerically from Digital Holography [132]. Thus one can choose the interferometric technique (hologram interferometry, shearography or other techniques) after hologram recording by mathematical methods.

The use of electronic devices such as CCD's for recording of interferograms was already established in Electronic Speckle Pattern Interferometry (ESPI, also named *TV-holography*), discovered independently from each other by Butters and Leendertz [12], Macovski, Ramsey and Schaefer [96] and Schwomma [141]: Two speckle interferograms are recorded in different states of the object under investigation. The speckle patterns are subtracted electronically. The resulting fringe pattern has some similarities to that of conventional or digital HI. Main differences are the speckle appearance of the fringes and the loss of phase in the correlation process [29, 94, 95]. The interference phase has to be recovered with phase shifting methods [19, 152, 153], requiring additional experimental effort (phase shifting unit). Digital Holographic Interferometry and ESPI are competing methods: The image subtraction in ESPI is easier than the numerical reconstruction of Digital Holography, but the information content of digital holograms is higher. ESPI and other methods of speckle metrology are also discussed in this book in order to compare them with Digital Holographic Interferometry.

Since mid nineties of the last century Digital Holography has been extended, improved and applied to several measurement tasks. Important steps are:

- improvements of the experimental techniques and of the reconstruction algorithm [21, 23, 24, 27, 28, 33, 43, 44, 66, 68, 72-76, 85, 98, 104, 116, 120, 121, 124, 134-136, 139, 148, 167, 175],
- applications in deformation analysis and shape measurement [18, 59, 70, 109, 110, 119, 133, 138, 142, 143, 163, 180],

- the development of phase shifting digital holography [30, 45, 54, 62, 86, 146, 165, 171-174, 178, 179],
- applications in imaging, particle tracking and microscopy [5, 6, 7, 22, 32, 55, 65, 67, 77, 114, 122, 123, 137, 158, 159, 160, 168, 169],
- measurement of refractive index distributions within transparent media due to temperature or concentration variations [31, 63, 64, 115, 166],
- applications in encrypting of information [56, 84, 155, 156],
- the development of digital light-in-flight holography and other short-coherence-length applications [13, 61, 101-103, 117, 126],
- the combination of digital holography with heterodyne techniques [88, 89]
- the development of methods to reconstruct the three-dimensional object structure from digital holograms [34, 35, 57, 97, 157, 177]
- the development of comparative Digital Holography [111, 112]
- the use of a Digital Mirror Device (DMD) for optical reconstruction of digital holograms (DMD) [78].

This book is structured as follows: Optical foundations and the basic principles of holography are discussed in chapter 2. The third chapter describes the process of digital hologram recording and the various methods of numerical reconstruction. Digital Holographic Interferometry is discussed in chapter 4. The fifth chapter is devoted to Digital Holographic Microscopy. Special applications and techniques like short coherence recording, particle field applications and comparative holography are described in chapter 6. In the last chapter 7 speckle metrology techniques are discussed and compared with Digital Holographic Interferometry.