EXPERIMENTAL INVESTIGATION OF THE RECORDING MATERIAL USED FOR HOLOGRAPHIC MEMORY SYSTEM

Results of the PhD thesis

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Introduction

The topic of my PhD thesis is the holographic data storage, which is in the focus of the research because of its perspective. The 3 dimensional property of the storing material is exploited by a unique recording technique called multiplexing, which means multiple recording of holograms on the same volume of the data carrier, thus enabling higher capacity or hardware encoding. However the complex system demanding special complicated implementations remained in turn as test instruments of research laboratories. Everybody agreed, the concept is great, but until its optical and opto-electronical elements have been cheaper and there has been appropriate recording material, the progress is hard. In the beginning of the 21st century there are novel results in opto-electronics and material research, which are promising for the future.

The Atomic Physics Department of the Technical University of Budapest in collaboration with Optilink Ltd. has been developing a holographic memory card system [1,2,3,4]. The basis of the system is an azobenzene side-chain polyester [5] produced by RISØ National Institute of Denmark, which becomes anisotropic due to absorption of linearly polarized light of proper wavelength. Such a material can record polarization hologram [6]. The polarization holography differs from conventional holography in many respects. The most essential difference is that the polarization hologram can record the modulation of polarization direction apart from intensity modulation of the recording electric field.

Background

Holme et al. investigated experimentally and theoretically the holographic diffraction occurred in azobenzene side-chain polyesters [7,8]. During polarization holographic recording they observed that apart from anisotropic grating surface grating was coming into being. That was proved by atomic force microscopic measurements [9]. They developed a theory which describes well the low efficiency holographic diffraction obtained by small angle writing beams. Using this theory the phase shift and diffraction efficiency caused by anisotropic and surface grating can be determined. The diffraction on surface grating is insensitive to the polarization of the readout beam, which is undesirable for the holographic storage system using polarization holography. The creators of the model haven't investigated how a covering layer affects the surface grating. A hard covering layer is necessary in any case to protect physically and chemically the recording layer. Thus it is an important question, how and to what extent forms the surface grating in this case?

The light scattering property of the optical data storing materials can be a limiting factor [10]. This feature is of special interest in case of holographic recording materials [11], where the diffraction efficiency must exceed the efficiency of the scattered light to achieve appropriate signal to noise ratio. In case of polarization holographic recording materials the polarization of the scattered light is important as well. Using orthogonally circularly polarized writing beams the polarization of the diffracted hologram is orthogonal to the readout beam. Thus it is essential to know how the amorphous and liquid crystalline polymer scatters the light? What is the absolute value of the light scattering, its polarization condition and the possible relation to the material composition and structure?

In optical data storage the decrease of the applied wavelength is an obvious method to enhance the storage density, since this lowers the limiting role of the optical diffraction, thus the bit size could be smaller. In holographic data storage there is a further technique i.e. multiplexing [12] to increase the capacity, which means multiple recording of holograms in the same volume of the carrier. The multiplexing ability of the recording material is given by the M number (M#), which determines the achievable number of multiplexed holograms at a given hologram efficiency. In order to study possible enhancement of the data density with the wavelength in azobenzene polymers it is worth to investigate the sensitivity and M# at lower wavelength (407 nm) then presently used (532 nm) in the holographic memory card system.

In holographic data storage Fourier holographic recording [13] is used to decrease the hologram size, which means that the Fourier transformed object is recorded in the storing material. This has the drawback that there are huge intensity peaks in the 0. and higher orders of the Fourier space, which saturates the recording material degrading its recording capabilities. To avoid this effect a random phase mask is put in the object beam [13], which disturbs the interference of the rays coming from the object pixels, thus the intensity of the peak is decreased. Another technique to avoid the saturation is to move the hologram out from the Fourier plane [13], however this has the consequence that the hologram size increases, which might lower the data density. The writing system can be optimized with exact knowledge of the saturation behavior of the recording material. Therefore it is worth to carry out experiments with high intensity ratio object and reference beams to discover the saturation behavior of the recording material.

Results

The aim of my PhD work was to investigate experimentally the recording material used for holographic memory system developed by Optilink and BUTE Atomic Physics Department. Within this work I responded the questions asked in the background chapter and carried out the suggested experimental investigations. The results can be summarized in 4 points.

1. Using the theory created and experimentally proved by Holme I showed that during polarization holographic recording in azobenzene side-chain polymer the anisotropic grating is coming faster into being than the surface grating. The effect of surface grating is negligible in polymer samples with hard covering layer, because it mostly hinders the formation of surface grating. I proved when only anisotropic grating occurs, the recording material is

rewritable and recorded information can be erased by the reference beam [14, 15].

2. I investigated the angular light scattering and the polarization of the scattered light of amorphous and liquid crystalline polymer layers. The intensity of scattered light is lower with orders of magnitude in case of amorphous polymer samples than in liquid crystalline samples, where the main scattering centers are the domains of the liquid crystal structure. I determined the size of domains using polarization microscope and in indirect way calculating back from light scattering results. I treated the domains as slits, and supposed that the light diffraction on slits causes the typical scattering spectrum in the $\pm 10\text{-}80^0$ region. The theory gave good agreement with the experiments, according to the observation the lower limit of the domain size can be determined from the light scattering results. I proved that in case of amorphous polymers using circularly polarized probe beam the efficiency of orthogonally polarized scattered light is negligible to the parallel polarization of the scattered light. In case of liquid crystalline polymer the orthogonal polarization part of the scattered light is so high that it exceeds the efficiency of the orthogonally polarized hologram [16, 17].
3. I investigated the sensitivity and the multiplexing ability of the storing material at different wavelengths: 407 nm and 532 nm. I showed that the sensitivity of the material is 3-14 times higher at lower wavelength depending on polymer type, but the multiplexing ability is the same for both wavelengths, which means that the material can be faster addressed at lower wavelength, but it erases faster due to irradiation with reference beam as well. The maximum value of the M# is 0.32, which means 10* multiplexing in case of 0.1% hologram efficiency [18].
4. I investigated the behavior of the recording material in case of extreme intensity ratios which easily occur in Fourier holographic recording. To model experimentally this phenomenon I recorded holograms with high intensity ratio ($I_{object}/I_{reference} \leq 500$) plane waves. I proved that beyond an optimal intensity ratio the recording material cannot be addressed, it saturates, which manifests in diffraction efficiency decrease. This optimal intensity ratio is inversely proportional to the reference intensity. My colleagues proved theoretically the experimental results, and the simulation of the holographic memory card system extended with this theory proved indirectly my experimental results [17, 18, 19, 20, 21, 22].

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