Design of a planar-integrated r/w-head for holographic data storage

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A novel systems approach for a r/w-head for holographic storage disks is proposed. It is based on the design principle of planar-integrated free-space optics and on the use of a particular photopolymer as storage material: phenanthrenequinone-doped polymethylmethacrylate (PQ:PMMA). Experimental results about the fabrication and the optical performance of PQ:PMMA are presented.

1 Indroduction

The concept to store (digital) data holographically is almost as old as the laser [1] and has attracted a lot of scientific attention during the past four decades because it promises a truely 3-dimensional data storage with high capacity and density, and inherently offers parallel, page-oriented and optionally associative (i.e. content-addressable) data access. Despite these interesting features, holographic memories have (so far) not experienced the same commercial success as other optical information technology hardware (e.g. optical fibers, CD/DVD). Reasons were twofold in the past: Strong limitations concerning suitable photorefractive storage materials and a lack of system implementations that are low-cost but robust enough for an out-of-the-lab use. With respect to both issues considerable technological progress has been made in recent years that is now propelling R&D activities on hologrphic data storage and may eventually lead to its commercial breakthrough [2]. In this context we propose a system approach that addresses both the material and the implementation issue by applying the concept of planar-integrated free-space optics (PIFSO) for the setup and by using the novel photopolymer PQ:PMMA as storage material.

2 Planar-integrated holographic r/w head

The key feature of PIFSO is to "fold" a free-space optical system with the desired functionality into a planar transparent substate in such a way that optical signals propagate along zigzag paths inside the substrate and that optical components are located at the surfaces [3]. The monolithic integration makes PIFSO setups both compact and rugged, lithography- and replication-based techniques allow one to keep fabrication cost potentially low.

We apply the PIFSO principle for the construction of a r/w head for holographic memory disks. Fig. 1 shows the proposed reflection-type Fourier optical system architecture in the recording and the read-out mode. One can recognize an orthogonal signal beam and two skew reference beam paths that intersect at a target position on the reflective lower side of the photosensitive layer of the memory disk in which the hologram is recorded. All beams originate from the same laser source from which they are coupled into the PIFSO system by single-mode optical fibers. The relay of the signal beam from the fiber end to the disk is carried out by a 4-f system; in its Fourier plane the expanded beam is 2-D spatially modulated by a LCD microdisplay. To be able to record a complete signal page without losses the diameter of the reference beams has to be matched to the width of the signal spectrum at the disk. The two reference beams are furthermore perfectly collimated and counter-propagating so that they can be considered as mutually phase-con

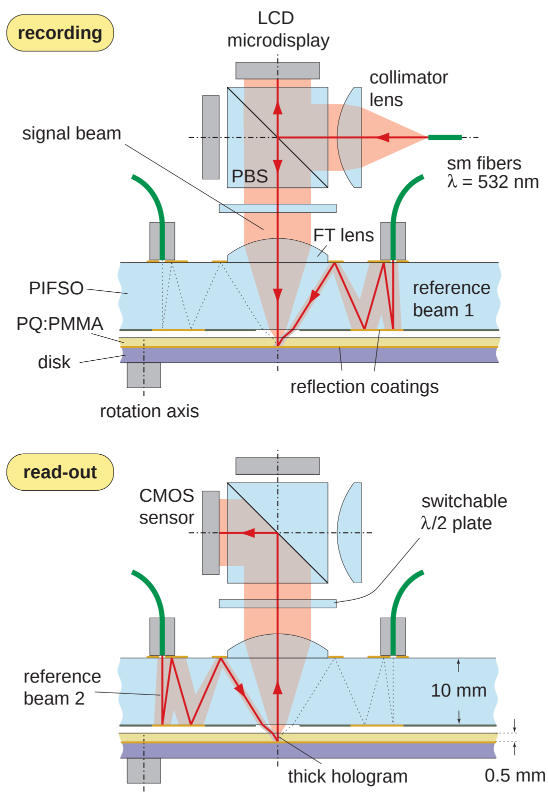

***Fig. 1** : Design and working principle of the proposed planar-integrated r/w-head for holographic data storage.*

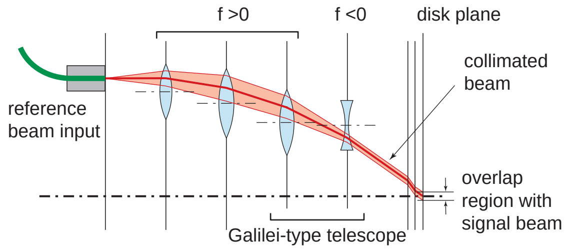

***Fig. 2** : Unfolded version of the reference beam relay.*

jugate. Hence, if reference beam 1 is used for the recording of a hologram then a read-out with reference beam 2 will generate the phase-conjugate version of the original signal beam; this reconstructed beam propagates through the 4-f system in opposite direction and is projected onto a CMOS sensor. The reference beam relay is carried out by an assembly of diffractive lenses that are operated off-axis to achieve a beam inclination of 30 deg.. From Fig. 2, which depicts an unfolded version of this optical subsystem, one can recognize that the beam width is adjusted by a Galilei-type telescope formed by the two lenses next to the disk plane.

3 PQ:PMMA photopolymer material

As recording material we propose a particular photopolymer, phenanthrenequinone-doped polymethylmethacrylate (PQ:PMMA)[4]. In this material PMMA serves as a host matrix that provides mechanical stability, and PQ as photosensitive dopant. The chemical structures of the main components of PQ:PMMA are shown in Fig. 3. Under illumination, PQ molecules react with residual MMA monomers in the PMMA matirx which leads to an intensity-dependant local change of the refractive index and thus to the generation of a phase hologram. Since this process is irreversible PQ:PMMA can be considered as write-once storage material.

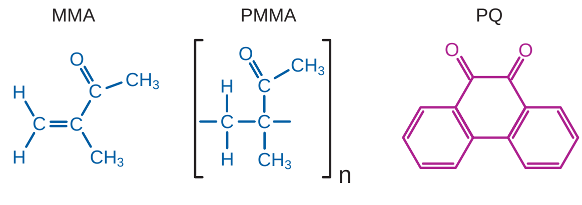

***Fig. 3**: Chemical structure of (poly)methylmethacrylate ((P)MMA) and phenanthrenequinone (PQ).*

Like other photopolymer materials PQ:PMMA exhibits a high senisivity and a large photo-induced refractive index modulation, it is relatively low-cost and can be processed easily (all this in comparison with inorganic photorefractive crystals like $LiNbO_3$). A particular difference to conventional photopolymers is that PQ:PMMA shows almost no shrinkage effect induced by the photochemical reactions of the recording process which would lead to a Bragg mismatch. This disturbing effect can effectively be suppressed by a fabrication process that generates a strong, volume-stable PMMA host matrix.

4 Experiments

In preparation for a practical realization of the set-up of Fig. 1 the fabrication process for PQ:PMMA was optimized. The best material samples were obtained using a two-step thermo-polymerization procedure that includes several dissolution, mixing, heating, and stirring steps [4]. With custom-designed casts PQ:PMMA samples of arbitary shape can be fabricated. As one can see from Fig. 4, the material has a yellowish color which disappears when the free PQ molecules are "consumed" by photochemical reactions during exposure.

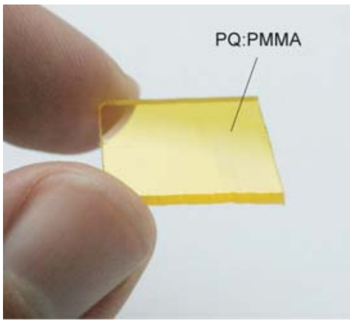

***Fig. 4** : Experimental PQ:PMMA sample*

An optical characterization of the fabricated material samples yielded the C(E) curve (cumulative grating strength vs. exposure energy) depicted in Fig. 5 from which M# = 2.06 and E_τ =4.76 J/cm^2 can be deduced.

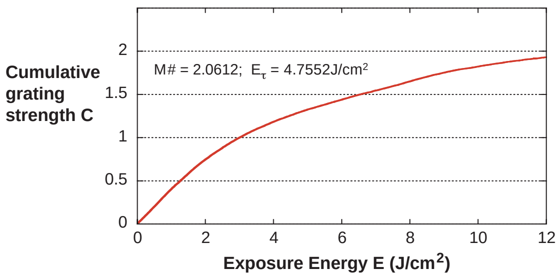

***Fig. 5** : Measured C(E) curve for PQ:PMMA (from [4]).*

References

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