Light-Sensitive Organic Recording Media for 3D Optical Memory

Valery Barachevsky; Photochemistry Center of the Russian Academy of Sciences; Moscow / Russia

Abstract

This paper presents the comparative analysis of the results including own data in the field of the development of organic recording media for 3D bitwise and holographic optical memory.

Introduction

Progress of information basis requires the improvement of the computerized technique in the direction of increasing its possibility to storage the large data massive and fast processing.

The analysis of the current status shows that, at the present time, well-known optical disks (ODs) provide storage and processing of 10% information only. Other information volume is saved on magnetic tapes and disks. It is anticipated that a limiting bit density of magnetic disks may achieve 150 Gbit/in^2 [1]. It may be increased up to 230 GBit/in^2 by application of a new technology of vertical writing [2]. In this case, information capacity of the magnetic disks may increase up to 20 GBytes. As this takes place, the rate of data processing will achieve 1 GByte/s.

The most information capacity may be achieved for ODs because laser radiation may be focused into a spot of a 1 μ diameter. In principle, it is limited by diffraction of optical irradiation only. The surface density my achieve $1/\lambda^2$. At present time, the one-layer ODs of a CD type (I) received a wide application. The manufacture of these ODs is based on application of photoresists. These ODs provide the manifold readout of optical information which was written in studio. There are ODs which provide once writing and manifold readout of optical information using computer only (WORM ODs, II). Writing is realized by thermoinduced ablation or transformation of vacuum-evaporated organic dyes or metals layers under laser irradiation. These ODs are acceptable for bitwise archival storage of optical information. There are reversible ODs providing manifold writing and erasure as well as readout of optical information (WERM ODs, III) under laser radiation as a result of thermoinduced remagnetization of domains in magneto-optical disks or phase transformations of the metal alloys. Information capacity of these disks with the use of red semi-conductive laser (650 nm) for writing and readout of optical information achieves 4,7 GBytes. The recurrence of reversible transformations may be about 100 writing-erasure cycles. The perspectives for following increasing information capacity of one-layer ODs are linked with the use of semi-conductive laser which is characterized by short-wave radiation. In principle, writing density may achieve 2.5.10 ^{9} bits/cm^2 with the use of UV laser (200 nm) [3] The Blu-ray Disc Association has been developed ODs of this type with information capacity of 25 GBytes (or 50 GBytes for DVD) using UV semi-conductive laser radiating at 405 nm and numerical aperture of 0.85 [4]. Other methods for increasing surface bit density are developing too. In particularly, it is suggested to use technology of writing in the near field using microscopes. According to this method irradiation goes through holes which have a small diameter as compared with the wave-length of activating irradiation. This irradiation traverses at shallow distance or the near field. Laser radiation is focused into a spot of 30 nm by lenses and projected on the light-sensitive layer of OD. In this case, the bit density may achieve 10^{11}-10^{12} bits/cm^2 [5]. At present time, ODs of this type with information capacity of 20 GBytes have been prepared. Besides, the new method which is based on application of matrices of silicon tips (100 tips/mm^2) provide bit writing by the method of mechanical irreversible and reversible action on the surface of a polymer film. The information capacity for the one-layer OD prepared by this method may achieve 112 GBytes [6].

The following perspectives are connected with making three-dimensional (3D) volume optical memory containing tens and hundreds light-sensitive layers. This optical memory may provide the bit density more 10^{12} bit/cm^3 or 1 Tbit/cm^3 [7].

This paper presents the comparative analysis of the results including own data in the field of the development of organic recording media for 3D bitwise and holographic optical memory.

Bitwise Two-Photon Organic Recording Media

Finding two-photon photochromism [8] and the following development of the principles for making two-photon 3D optical memory [9] deduced the large activity in the development of two-photon reversible media for 3D WORM and WERM optical memory. The most attention for data recording in the bit-organized 3D optical memory is focused on the light-sensitive materials with the photoinduced fluorescence [10].

Light-Sensitive Irreversible Media

The first experiments for making irreversible recording media for 3D WORM optical systems were received with the use of the irreversible acid photogeneration from 1-nitronaphthadegide and following transformation of nonfluorescent base of Rhodamine B into fluorescing dye [11,12]. The media of this type are being developed very active [13-16].

The irreversible photochemical reaction of dissociation aromatic azides, interaction between diarylamine and tetrabrommethane as well as diarylamine and acridine halide [17] and photolinking oligomers [18] may be used for the development of recording media with fluorescent readout for 3D WORM optical memory too.

Photochromic Media

The recording media for bitwise two-photon WERM optical memory require using the photochromic compounds confirming to following needs: thermal stability of two forms providing photoinduced reversible transformations, resistance to fatigue during cyclic write and erase processes, fast response, high sensitivity, nondestructive readout capability and large two-photon absorption coefficient [19].

Among the first investigated reversible recording media photochromic materials based on nitro-substituted spiropyrans were used for the development of 3D bitwise two-photon WERM optical memory [18,20,21].These recording media provide fluorescent readout. Unfortunately, these compounds are characterized by thermal instability of the photoinduced form and a limited number of cycles for photochromic transformations. Nonetheless, these materials were used for the development of the optical devices [20-28]. At the last time, the thermal stable spirooxazine with the high recurrence of photochromic transformations and photochromic polymethylmethacrylate film based on this compound were prepared [29].

Thermal irreversible photochromic recording media for the luminescent readout were developed with the use of the anthracene derivatives manifesting reversible dimerization [30-33] and perinaphthothioindigo exhibiting reversible cis-trans photoisomerization [34].

Among thermal irreversible photochromic compounds are photochromic phenoxy-derivatives of certain quinines manifesting reversible photoisomerization of the para - quinone structure to the ana - quinone one [35]. In spite of an intensive study [36-43], recording media based on these compounds have not attracted any considerable practical interest up to now. One of the reason is absence of photoinduced fluorescent changes for majority of these compounds .

Most of investigations is devoted to the recording media based on thermal irreversible diarylethenes (DAE) [44] and fulgides [45].

The comparative study of the spectral and kinetic characteristics for photochromic transformations of a number new thienyl - containing DAEs with the different five-member cyclic bridges has been carried out by us [46-49]. It was found that all compounds are characterized by high thermal stability of both forms. The spectral characteristics of studied DAEs depend on the nature of the bridges and the substituents. Compounds manifesting short-wavelength absorption bands of the cyclic form may be used for one-photon short –wavelength recording [50,51].

It was shown that DAEs manifest photochromic transformations in polymer binders [52-54], amorphous [55-58] and solid [59-62] states. These compounds meet requirements for the development of 3D recording media. The special attention is being given to high-content photochromic polymers based on DAEs [63].

DAEs reversibly change not only the absorption spectra but also other physical properties namely fluorescence, refractive index, polarizability, electrical conductivity and magnetism [64]. The photoinduced changes of these properties are used for readout of optical information [65].

The fluorescent readout method is more acceptable for this goal because of high sensitivity [44] but, usually, the fluorescence quantum yields of the DAE molecules were relatively small. Its may be increased by the structure design [66-70]. Unfortunately, excitation of DAE fluorescence leads to slow rubbing out of optical information. To illuminate of this phenomenon a number of hybrid DAE-based photochromic compounds providing nondestructive readout were synthesized [71-73].

The effective fluorescent method for nondestructive readout with the use of bilayers containing fluorescent and photochromic components was proposed [74].

For the same goal a number of other methods based on photoinduced change of refractive index [44,75, 76], intensity of IR absorption bands [44, 77-79], electroconductivity [80-86], optical Kerr effect [87,88] and optical rotation [89,90] have been developed.

Unlike DAE fulgides (X=O) and fulgimides (X=N-R) manifest not only photoinduced valence isomerization between open (E) and closed (C) forms but E-Z isomerization as well.

Among these compounds [45] the indolyl-derivatives of fulgides received primary emphasis for using in 3D optical memory because of the excellent fluorescent properties of the closed form [91-97]. Like DAE the nondestructive fluorescent method for readout of optical information based on hybrid photochromic compounds was developed [98-101].

The pyrryl-substituted fulgides were used for the development of recording media too [102-103].

We synthesized and studied the several new thienyl - containing fulgimides with the different substituents R. Absorption spectra of the open form E for these compounds exhibit absorption band in the field of 290-340 nm . Maximum of the absorption band for the cyclic form C is arranged at 520-540 nm. The position of this band depends on the substituent nature. The efficiency of the photocoloration process is reduced after introduction the substituent R undergoing cis-trans photoisomerization. Much like the DAEs , fulgimides are characterized by high thermal and photochemical stability of both forms.

Holographic Organic Recording Media

Photopolymerizable Media

Among recording media used in the technique holography the special attention to holographic CD optical disks for achieve optical memory possessing the super high information capacity is centered. For realization of this 3D optical memory the thick holographic recording media (up to 5 mm) providing the high information capacity on account of high angle selectivity of recording and readout of holograms are more tolerable [104]. High energetic sensitivity and large dynamic range are other important factors for application.

The advantages of the developed photopolymerizable materials to store information with high capacity and fast random access provided a progress toward the commercial realization of high performance holographic data storage [105,106].

Photopolymerizable materials containing thermal irreversible photochromic compounds from spiropyrans, DAE and photochromic quinines as sensitizers have been developed by us for archive optical memory of this type [107]. Application of photochromic compounds makes the process of light-sensitive layer desensitization more simple as compared with the photobleaching dyes [104].

Photoanisotropic Reversible Media

The possibility of making holographic working optical memory is connected with application of phase photoanisotropic media [104]. At the first time, it was shown that the photoanisotropic films based on poly(vinyl alcohol) and photochromic azodyes [108] allow to record two holograms at the same segment of the recording medium and spatial frequency by varying the polarization of recording light. In this case, there is possibility to use of one laser radiation with mutually perpendicular polarization. In principle, using polarize light provides nondestructive readout beyond the absorption band [109].

Conclusions

The analysis state-of-the art and perspectives for the development of recording media for 3D optical memory on ODs shows, that the main perspectives are linked with the development of multilayer ODs with information capacity of 1-10 [illegible]Bytes. The modern CDs may be changed by 3D holographic ODs based on photopolymerized recording media. The irreversible photochemical and photochromic organic materials with the fluorescent or refractive readout are acceptable for making irreversible and reversible ODs used in 3D bitwise WORM and WERM optical memory, correspondingly. Application of the developed photoanisotropic organic media in 3D holographic working memory is retarded by the complexity of holographic optical devices. The following improvement of recording media is required to practical realization of 3D optical memories of all types.

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Author Biography

Valery Barachevsky was born in 1937 and received his Ph. D in Physics from the St.- Petersburg State University, Russia. Now he is Head of Lab of the Photochemistry Center of the Russian Academy of Sciences. His work has primarily focused on the development and application different light-sensitive systems and materials, including of non-silver organic light-sensitive media for information technologies with use of bit-by-bit and holographic methods. He is a member of the SPIE and the editorial staff of the journal "Optical Memory & Neural Networks" (USA). He is author of 570 publications including 70 Russian and European patents