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Introduction

The Fifth International Symposium on Optical Storage was held 22–26 May 2000 in Shanghai-Pudong, People's Republic of China, under the auspices of National Natural Science Foundation of China, Chinese Society for Optical Storage, China Optical Disk Manufacturer's Association, and SPIE—The International Society for Optical Engineering. The symposium was organized by Shanghai Institute of Optics and Fine Mechanics (SIOFM), Chinese Academy of Sciences (CAS), and Tsinghua University. The four previous symposia in this series were held in Shanghai-Jiading (1988), Chonqing (1990), Kunming (1992), and Shenzhen (1996), respectively, and they have continued to grow over the years. More than 120 scientists, technologists, and experts from universities, research institutes, and industries of 12 countries and regions participated in the fifth symposium, which provided a forum for reviewing recent progress and exchanging information in a wide range of topics including materials, physics, media, drive, and measurement technologies in optical storage. This forum promoted discussion on both the theoretical aspects and practical applications of optical storage, and strengthened cooperation and friendship within the optical storage community.

Eighty-four papers were presented at the symposium, including forty-eight as oral presentations in seven technical sessions and thirty-six as posters. From these papers, invited and contributed, oral and poster, it can be seen that interest in high-density and high-data-rate optical storage has become a dominant trend. Materials, technologies, components, and devices for HD-DVD (high-density DVD) have been attracting more and more research and development activities apart from the digital versatile disk (DVD) technology. Certainly, some new mechanisms, materials, and formats for optical storage have emerged. But due to the limitation of space, not all the presented papers can be published in this volume. The 69 papers published here cover the development and challenge of optical storage, magneto-optical, phase-change, and organic media, disk manufacturing technology, mastering, drive, testing, and applications, as well as high-density optical storage.

We are very grateful to the members of the International Advisory Committee, the Organizing Committee, and the Program Committee, as well as the session chairs for their fruitful work in the preparation and operation of the symposium. Thanks are also extended to our invited speakers and all of the contributing authors for their elaborate preparation of abstracts for the advance program and manuscripts for these proceedings. We also gratefully acknowledge the sponsors and cosponsors, domestic and abroad, without whose support we could not have held such a successful symposium.

Fuxi Gan

Contents

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Invited Paper

Super high-density optical storage in China

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ABSTACT

This paper gives a review of the new progress in the super high-density optical storage research in China. The main research fields are short wavelength optical disk storage, near field optical storage, digital holographic storage and photo-induced multi dimensional storage. General remarks of the super high-density optical storage research are also given.

Keywords: optical storage, high-density, short wavelength, near filed, holographic, photo-induced, multi dimensional

1. INTRODUCTION

21[st] century is the Tera-bit information century. The process, transfer and storage of the Tera-bit information should possess the characteristics of super high-density and super high transfer rate. In recent years, optical storage has been a very rapid development in response to the ever-growing demands. The trend of optical storage development is from infrared recording wavelength to ultraviolet recording wavelength; from far field optical recording to near field optical recording; from 2-dimensional storage to multi dimension storage; from photo-thermal effect to photo-induced effect. The optical storage research and development were started in 1985 in China. ϕ130 mm magneto-optical and phase change disks and ϕ120 mm recordable disks were developed in 1990 and 1996, respectively. More attention has been paid into high-density optical storage recently: short wavelength (~ 500 nm) recording, near field optical recording, digital holographic recording, and photo-induced multi-dimensional storage. This paper gives a review of the new progress in the super high-density optical storage research in China.

2. SHORT WAVELENGTH OPTICAL DISK STORAGE

Chinese Academy of Sciences is conducting a super high-density optical disk storage project (HD-DVD). The objective of ϕ 120 mm HD-DVD is 20 GB storage capacities on single side, which means the minimum mark length is about 200nm, storage density is about 10-20 Gb/in^2. The write/erase cycle is larger than 1000 times and data transfer rate is about 50Mb/s. The solutions include shortening laser wavelength by adopting 400~500 nm GaN lasers, enlarging numerical aperture of objective lens from 0.65 to 1.0, using super-resolution detection methods, such as optical super resolution, magnetically induced super resolution (MSR), and SUPER-RENS, shortening track pitch distance to 300~400 nm, improving encode, format, and write/read strategies, such as zone constant angular velocity (ZCAV), zone constant linear velocity (ZCLA), sampling serve (SS), mark-edge recording, land-groove recording and so on.

High-density optical storage media materials must meet a series of special requirements. Considerable work has been carried out in Chinese Academy of Sciences. Three kinds of magneto-optical materials have been studied: Pt /Co, or Pd/Co multilayer films, MnBiAl films and garnet films[1]. To meet the needs of high-density information records, MO materials should have large Kerr rotation at short wavelength, large coercivity and fine grain size. The effects of doping different third elements in Co or Pt (Pd) layers are studied, such as Cu, Al, Ag, Ni, Fe[2]. Different preparing conditions have been tried, including Ar pressure, substrate temperature, annealing temperature and time and so on[3]. MnBi films have been modified by doping with different elements, such as Al, Au, Ag, In, Pt, Sb, Si and RE[4]. For garnet films, the influences of doped ions have been studied, such as doping Bi to increase Faraday rotation, doping Cu or RE to increase coercivity, doping Ga, Al to increase Faraday rotation and coecivity and to reduce M_S and T_C[5,6]. The optimum design of disk structure such as reflective layers and thickness of garnet films has also been studied.

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Fig. 1 shows the curves of the saturated polar Kerr rotation θ_k vs. wavelength as the function of the doping concentration of Ni in the Pt spacer layer[7]. An enhanced magneto-optical effect appears in PtNi/Co multilayers at small dopings, for example, x=0.08, in 400 nm to 800 nm region. Fig.2 is the magnetic and magneto-optical properties of PtFe/Co multilayers. 20% enhancement of polar Kerr rotation are obtained in PtFe/Co multilayers when x=4.2% at 400 nm wavelength[8]. It's assumed that the fluctuation of the Kerr rotation is due to the change of spin-polarization in PtFe spacer layers as a function of Fe doping content.

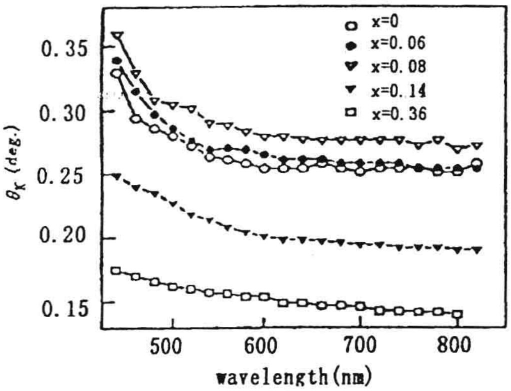

Fig. 1 The saturated polar Kerr rotation θ_k vs wavelength as the function of the doping concentration of Ni in the Pt spacer layer[7].

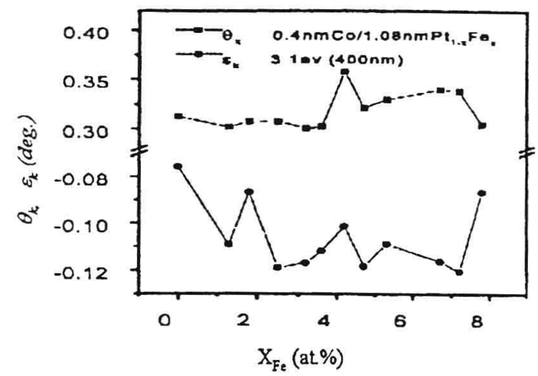

Fig.2 The magnetic and magneto-optical properties of PtFe/Co multilayers[8].

Several years ago Al modified MnBiAl film was reported that the grain size was reduced to 40 nm, and Kerr rotation increased 2 degree at red wavelength, but no enhanced effect was found at blue wavelength. Now we can see from figure 3 that the Kerr rotation can be largely enhanced at short wavelength shows in Mn $Bi_{0.47}Al_{0.15}$ film[9]. At photon energy of 3.3 eV, that is a wavelength of 376 nm, the remnant Kerr rotation is as large as 2.25 degree.

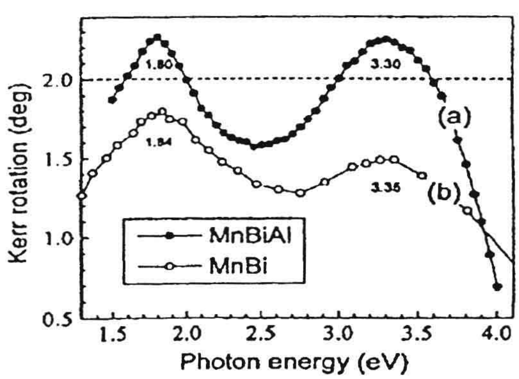

Fig. 3 The Kerr rotation spectrum of Mn $Bi_{0.47}Al_{0.15}$ film[9].

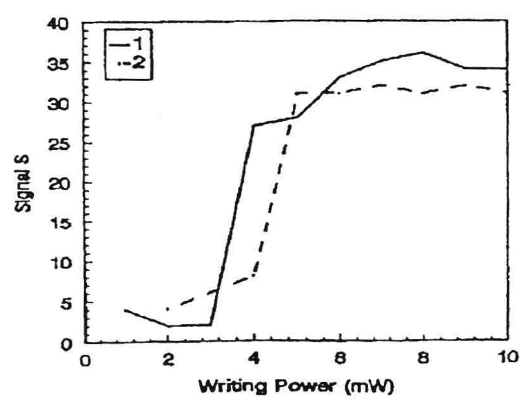

Fig. 4 The magneto-optical signal S of Bi, Ga, Cu doped DyIG film versus writing laser power for various laser duration times[10].

Doping Cu to Bi, Ga substituted DyIG film can greatly increase the coercivity. The highest of 16 K Oe has been reported. At the same time, the film still has large rotation angle at 510 nm. Fig. 4 shows the magneto-optical signal S of Bi, Ga, Cu doped DyIG film versus writing laser power for various laser duration times. The wavelength of the laser is 514 nm. The solid line is for 600 ns writing pulse, the dashed lines for 250 ns. The reading power is 0.8 mW, reading pulse width 300 ns, applied bias field 400 Oe. This suggests the materials can be used for short wavelength optical storage[10].

Phase change materials are promising rewritable optical storage materials. Great efforts have been made to push these materials to short wavelength recording[11]. Different compounds have been used for short wavelength storage. such as Ge-Sb-Te system and Ag-In-Sb-Te system. Ge_2 Sb_2 Te_5 film owns high complex refractive change between crystalline state and amorphous state even in short wavelength. Fig. 5 shows the measured extinction coefficient of $Ge_2Sb_2Te_5$ films annealed at different temperature[11]. Fig.6 shows the static optical storage performance of $Ge_1Sb_2Te_4$ film[10]. The wavelength of laser light is 514.5 nm. Large reflectivity contrast is obtained. Ag_{13} In_{16} Sb_{33} Te_{36} film has a high refractive contrast at short wavelength but the write/erase cycle times are limited. Ag_8In_{14} Sb_{55} Te_{23} has good erasability at short wavelength.

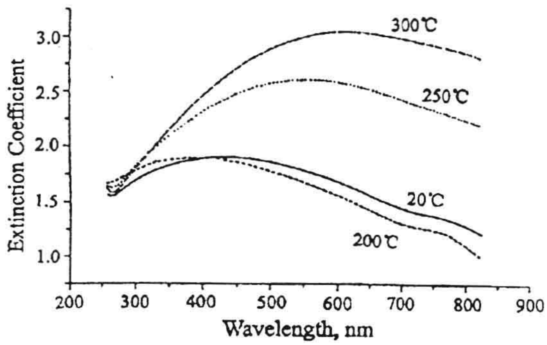

Fig. 5 The measured extinction coefficient of $Ge_2Sb_2Te_5$ films annealed at different temperature[11].

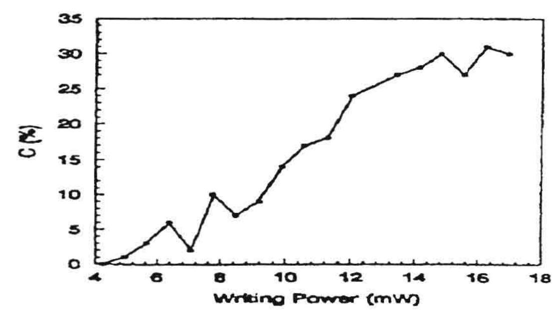

Fig.6 The static optical storage performance of $Ge_1Sb_2Te_4$ film[10].

The third kind high-density storage material is organic material, such as azo-dye materials[11]. Fig. 7 shows the optical storage performance of a novel push-pull azo dye doped PMMA film prepared by spin coating method as a function of wavelength. The strong absorption of at around 500 nm is favorable to the use of the dye for optical storage at green laser wavelength. When the writing power is higher than 13.3 mW, a refractive contrast as high as 25% can be obtained.

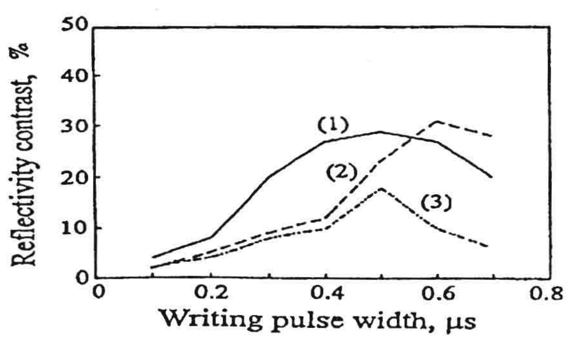

Fig. 7 The optical storage performance of azo dye doped PMMA film prepared by spin coating method[11].

Fig. 8 The STM image of an umbrella-like recorded pattern on CPU monomer thin film[19]..

3. NEAR FIELD OPTICAL STORAGE

The study on scanning near-field optical microscopy (SNOM) has been carried out in China for many years[12-16]. But study on the scanning near-field optical storage is the recent things. Several research groups in China are devoted into this field. A few fundamental works have been done. Simulation calculations for the energy transmission between the flying head and optical disc have been carried out[17]. Matrix solution of fiber-tapered wave-guide has been obtained[18]. Solid immersion lens have been designed and manufactured. Theoretical and experimental works on SUPER-RENS are under developed and being prepared. Super high-density storage by scanning tunneling microscope (STM) and atomic force microscope (AFM) has been reported. A novel organic compound, N-Cyano, N'-Phenyl, Urea (CPU) was synthesized and its thin film was prepared on highly ordered pyrolytic graphite substrate (HOPG)[19]. It was found that applying suitable voltage pulses between the tip and the thin film could form 0.8 nm recording marks in diameter. Fig. 8 shows the STM images of an umbrella-like recorded pattern on CPU monomer thin film obtained at Vb=0.49V, It=0.57 nA with a scanning rate of 0.2 Hz/image.

4. DIGITAL HOLOGRAPHIC STORAGE

Holographic storage possesses the characteristics of super high-capacity and super high date transfer rate. Many groups in China are devoted into this field. Their interests include holographic storage materials, such as $LiNbO_3$ photorefractive crystals doped or co-doped by different irons, azobenzene side-chain polymer with photoinduced anisotropy effect; volume holographic storage; holographic optical disk storage; nonvolatile holographic storage and so on.

As many as 1000 digital images have been recorded in a common volume of a Fe:LiNbO3 photorefractive crystal using angular multiplexing[20]. The combination of the error-correcting encoding and the differential encoding results in a significant noise-tolerant feature and thus a lower bit-error rate is achieved. This figure shows the schematic illustration of the experimental setup volume holographic storage in a Fe:LiNbO3 crystal by using of angular multiplexing. 1000 digital images have been recorded in a common volume.

Some researchers are studying a different set of photorefractive materials for large-scale applications: photorefractive polymers. Photoinduced anisotropy and high-efficiency optical storage in azobenzene side-chain polymer have been studied[21]. Measurements reveal that the polymer possesses large magnitude of photoinduced birefringence ($\Delta n 7.8 X 10^{-3}$). A reversible polarization hologram with high efficiency (19.3%) is recorded with a CW 532 nm laser in this thin film.

Several years ago a novel image parallel storage technique based on holographic optical disk storage theory was proposed. This is the parallel readout system of holographic optical disk. The parallel addressing/tracing technology has also been discussed in detail. Experimental disk-type 3-D holographic storage in a photorefractive crystal was reported by a team supervised by Prof. Tao last year[22]. 2000 high-resolution images have been stored in a disk-type photorefractive LiNbO3:Fe crystal using spatioangular multiplexing with a spherical reference wave[23]. They named it as spatioangularly multiplexed holographic disk (SAMHD). The holographic spots are allowed to overlap partially and to be distinguished from one another by use of different-angle reference beams. This strategy will simplify the optical storage setup, minimize the cross-

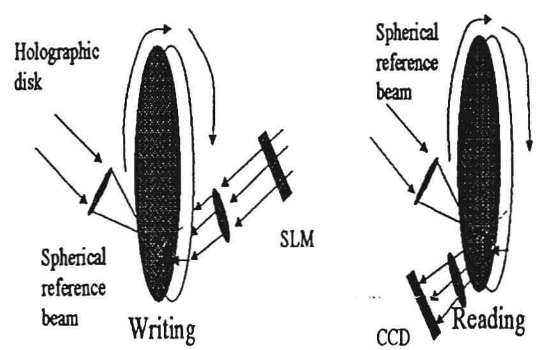

Fig. 9 The schematic diagram of SAMHD[22].

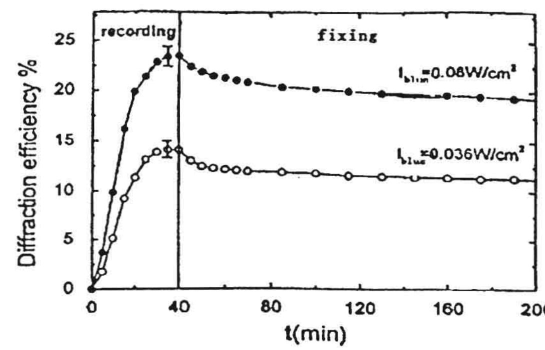

Fig. 10 The holographic recording and fixing characteristics of an oxidized LiNbO3: Cu: Ce with blue-light –red-light scheme[25].

talk of adjacent tracks, improve the storage capacity and improve the diffraction efficiency. Fig. 9 is the schematic diagram of SAMHD. Recently multi-track storage of 10,000 holograms in a disk-type photorefarctive crystal is studied. The disk contains 5 tracks[24].

One way to record holograms more permanently in $LiNbO_3$ is to "fix" them. A team form SIOFM have reported experimental and theoretical studies of Nonvolatile photorefractive holographic recording in LiNO3: Cu:Ce crystal with two illumination schemes[25]: (1) UV light for sensitization and a red interfering pattern for recording and (2) blue light for sensitization and a red pattern for recording. Fig. 10 is the holographic recording and fixing characteristics of an oxidized LiNbO3: Cu: Ce with blue-light –red-light scheme. The results show that the saturation diffraction efficiencies with the blue-light-red-light scheme are generally lower than those obtained with the UV-light-red-light scheme, the nonvolatile diffraction efficiencies are much higher for the blue-light-red-light scheme. It was also shown that there is an optimal red-to-blue intensity ratio for reaching maximum saturation and achieving the nonvolatile refractive-index modulation.

5. PHOTO-INDUCED MULTI DIMENSIONAL STORAGE

Photo-induced storage can be realized by different methods. These strategies have been studied by Chinese scientists: spectral hole-burning, photochromic effect, electron trapping, biology molecules, photo-induced nonlinear effect, two-photon absorption-based 3-D recording, 3 D data storage in glasses by fs laser.

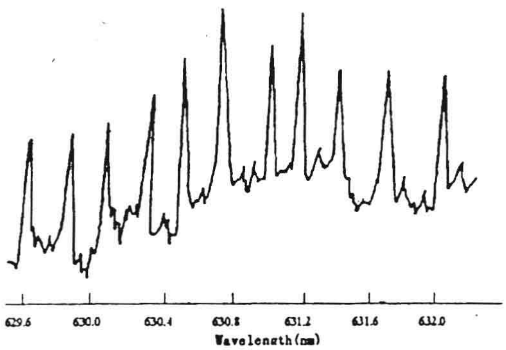

Fig. 11 The multiple photo-gated PHB of TZT/AC/PMMA[26]

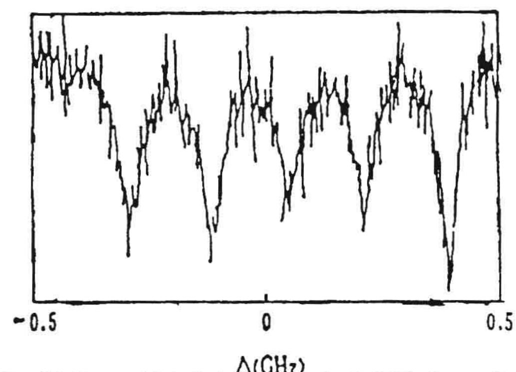

Fig. 12 The multiple hole-burning in $BaFCl_{0.5}Br_{0.5}$: Sm^{2+} at 2.3 K[26]

Considerable work has been done in photo-gated spectral hole burning storage[26]. Different kinds of materials have been designed and prepared. And the mechanisms have been studied. These materials include organic and inorganic systems, such as the derivative of Zn-tetrabenzoporphyrin, TPTBPZn/aromatic cyanide AC/PMMA, 1000 holes can be burnt at 4.2K; ZntbP/CA/PhR, 155 holes were burnt at 20K; inorganic $M_yM'_{1-y}FCl_xBr_{1-x}$:Sm^{2+}system, M, M'~ Ca, Mg, Ba, the $\triangle v_i$ is about 1000GHz and 5000 holes can be burnt at 2.3K; the first hole burning experiment at room temperature was realized in this system; Inorganic $SrBa(SO_4)_2$: Sm^{2+}; microparticle based hole burning at room temperature and hole burning in Eu^{3+}:Y_2SiO_5 crystal[27-29]. Fig. 11 shows the multiple photo-gated PHB of TZT/AC/PMMA. Fig. 12 is the multiple hole-burning in $BaFCl_{0.5}Br_{0.5}$: Sm^{2+} at 2.3 K. The central wavelength is 630 nm, and the scanning range is about 1 G Hz.

Photochromic storage is considered to have the potential to use in near field optical storage and 3D optical storage. Different kinds of photochromic recording compounds have been synthesized, such as spiropyran, fulgides, salicylidene-aniline and organnometallic complexes[26]. Recently, a multi-valued photochromic optical disk storage is carried out by static testing on pyrrole fulgide derivative film[30]. Fig. 13 shows the static testing result of four-valued photochromic storage.

Electron trapping materials are a kind of novel erasable, rewritable optical storage media. These materials can trap and release electrons with input photons[31, 32]. They have also shown inestimable promise for use in optical computing and optical information processing fields because of their many attractive characteristics, such as high write/erase speeds (less than 5 ns), limitless erasability, multilevel digital recording, capable of 3 dimensional storage, high SNR, realizing optical storage and information processing at the same time[33]. Many kinds of electron-trapping materials and electron tapping thin films are produced, such as Eu, Sm or Ce, Sm co-doped SrS or CaS. In these case, Ce ions were added as the dominant activators (luminescence centers) [34]. Fig. 14 shows the recorded images in SrS:Eu, Sm –PMMA film. Multilayer volumetric storage

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