Novel Optical Architecture for High Capacity and High Data Transfer Rate Holographic Data Storage

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Abstract: A novel optical system architecture employing local holographic recording with a pico-second pulsed fiber laser and a small page size SLM has the potential towards realizing compact, high capacity and high data transfer rate optical storage.

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1. Introduction

Holographic data storage (HDS) has been of interest as one of the promising optical recording architectures having high recording density and high data transfer rates. In HDS, a two-dimensional data pattern of a spatial light modulator (SLM) is recorded in a photo sensitive recording material as a Fourier volume hologram by interference with a reference beam. Volume holograms are superimposed with in the same location of the recording material by, for example, changing the incident angle of the reference beam. Upon readout, the Fourier volume hologram is inversely Fourier transformed by a lens and the signal is detected by two-dimensional detector arrays. As proof of capabilities of a HDS system, in the Optical Data Storage Conference 2009, SONY has reported a recording density of 415Gbits/inch^2. Also IBM reported 250 Gbits/Inch^2 in 2001. In 2000, Stanford University demonstrated data transfer rate of 10Gbits/seconds. So far, improvements in recording density and data transfer rate have been pursued separately. As a result, there is no published report on HDSs having both high density AND high data transfer rate.

In HDS, especially a system having a large number of pixels in the SLM, there is a fundamental trade-off between recording density and data rate. To achieve high recording density, a large number of multiplexed volume holograms is required which reduces the diffraction efficiency, or signal level. Consequently, readout requires a long integration time to achieve reasonably high SNR, which ends up with a low data transfer rate. Also, to achieve a high data transfer rate, a large number of pixels on the SLM (~1 mega pixels) is required. The requirement imposes a limited selection of usable detectors, i.e., CCD/CMOS detector arrays. In general such detectors need a couple of million photons to have a good SNR. Under limited laser power, again data rate needs reduction to have sufficient integration time. Recently, an optical architecture writing a single hologram as a data bit and a rotating disc has been proposed. This architecture is attractive especially because we have more flexible choices in laser sources and detectors [1]. However, the data transfer rate is ultimately limited by rotation speed of disc (12k RPM).

To overcome such trade-off between data transfer rate and recording density in HDS, we propose and analyze an alternative optical architecture by using a SLM having a small number of pixels (~10) combined with a high-repetition rate and ultra-short pulse fiber lasers, a layered medium, and high speed photo detectors. We also report experimental results of writing holograms using a ps-fiber laser as a proof of concept for the proposed optical architecture.

2. Optical Architecture

Recently, compact and high repetition all fiber laser systems became available. The repetition rate exceeds 100 MHz and power is on the order of 100 mW. Such a high repetition rate pulsed laser enables single pulse writing of a hologram with a GHz data transfer rate by a small number of pixels on the SLM, for example 10 pixels. Such a small pixel number configuration opens up a new opportunity for a HDS system because an unconventional high speed SLM, such as a Magneto-Optical SLM (MOSLM), having a GHz refresh rate can be used [2]. High speed detectors are usable since no massive data transfer inside the photo sensor array is required anymore. Also, a small pixel system has a fundamental advantage, namely localized recording. Localized recording enables effective usage of the dynamic range of the material when it is combined with a layered medium [3]. Finally, such a small number of pixels enable using scanning optics, not imaging optics which requires ultra-low distortion imaging for a large field of view. A schematic of the optical architecture is shown in Fig. 1. The system employs a two-step localized recording in the 90 degree geometry using a high repetition rate fiber-based pulsed laser, a SLM with a small number of pixels, scanning optics and a layered medium. During recording, a ultra-violet (UV) gating light is delivered to one of the layers of the recording medium. The gating light sensitizes the recording material to recording light in the infrared (IR) region [4] The recording IR light is modulated by a magneto optical SLM having a small number of pixels (i.e., 16 pixels in 4 by 4 format). The modulated light interferes with the reference beam delivered from one side of the layered medium. Thus the recording is carried out in a 90 degree geometry which has an advantage in terms of maximizing the number of storable holograms by using angular multiplexing and reducing scattering from the material to the detectors. For readout, gating light is turned off. The reference beam is delivered from the opposite side of the crystal, which is diffracted by the written hologram. Thus the recorded signal is reconstructed in a phase conjugate readout scheme. The proposed configuration using a layered medium allows selective writing and erasure of a single layer while not erasing the information stored in other layers. In addition, the phase conjugate readout does not require 1 to 1 pixel imaging, therefore, no highly precise alignment of optics is required. Recording capacity and data transfer rate is estimated 200GB/cm^3 and 375 Mbit /sec, respectively for the system having NA 0.515 optics and 35,000RPM polygon scanner. Detailed system design, including lens design of the scanning optics, optics for the recording layer selection and analysis of the data transfer rate, capacity will be discussed.

3. Experiments

A volume hologram has been stably written using a MOPA chirped pulse fiber laser system including a seed oscillator and amplifier. The repetition rate of the laser is 66MHz, the pulse length is 1 pico second with a maximum pulse energy of 10nJ/pulse, the wavelength is 1030nm with a spectral bandwidth of 4 nm. A train of 1 ps pulses (λ=1030nm) is delivered by the laser head. Through a second harmonic generation crystal, the frequency is doubled and the 515nm light is picked up by the dichroic mirror. As a recording material, Fe-0.015%-$LiNbO_3$ (size: 10x10x20mm, Deltronic Crystal Industries) has been used. The diffraction efficiency of the hologram is monitored by using a probing beam from a He-Ne laser (λ=633nm). Figure 2 shows the diffraction efficiency of the hologram as a function of time. The power of the green beams is 4.4mW and the beam diameter defined by $1/e^2$ intensity is 4 mm. The saturation diffraction efficiency is estimated at about 2.7e-3. The sensitivity defined by $(\partial\eta^{1/2}/\partial W)/L$, where, η is diffraction efficiency, W is an energy density and L is a thickness of material, is 0.004 cm/J. The diffraction efficiency grows in a similar manner as for holographic recording using continuous wave lasers, which shows feasibility of holographic data recording using pico-second fiber lasers.

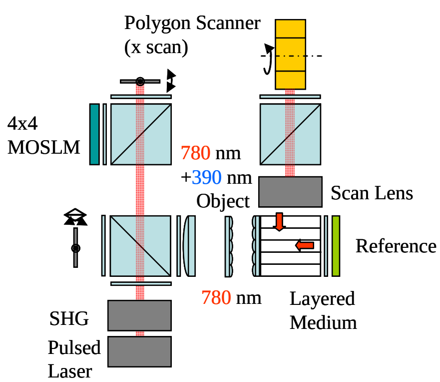

Fig. 1 A schematic of HDS with small number of pixels on spatial light modulator

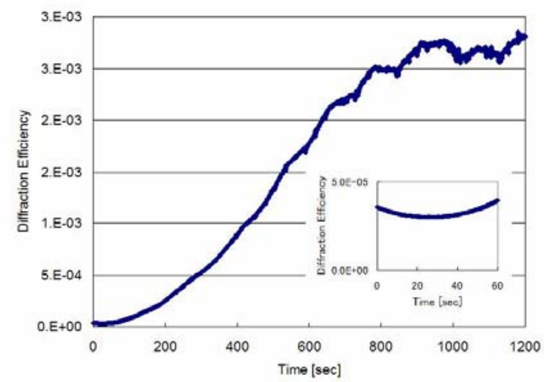

Fig. 2 Diffraction efficiency of hologram as a function of time

4. Conclusions

To overcome the trade-off between data transfer rate and recording density, we have proposed a novel optical system architecture using a spatial light modulator having a small number of pixels, ~16 pixels, compared to the 1 mega pixels which are typically used for conventional page-based holographic data storage, and a pico-second pulsed fiber laser. A 515nm pico-second pulsed fiber laser with a 66MHz repetition rate has been tested to write plane wave volume holograms in Fe-0.015% $LiNbO_3$ crystal. The diffraction efficiency grows in a similar manner to holographic recording using continuous wave lasers which shows feasibility of holographic data recording using pico-second fiber lasers.

5. References

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