ACOUSTO-OPTIC TUNABLE FILTER APPLICATION FOR VOLUME HOLOGRAPHIC MEMORIES

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Abstract

Volume holographic memories (VHM) provide an exclusive possibility to record, store, and retrieve data with high storage density. The most suitable tool to achieve high density is multiplexing. Several methods of multiplexing are known, and one of the most efficient ways is multiplexing by wavelength. The problem connected with wavelength multiplexing is that laser wavelength tuning in a wide range meets some problems. We propose to fix some of them using acousto-optic tunable filters (AOTF) which can select the certain spectrum lines from the total light beam in real time mode. The schematic representation of the proposed method has been demonstrated and described. The problems connected with AOTF spectrum resolution in accordance with the wavelength multiplexing method have been listed and discussed. The experimental features of AOTF developed by the authors are presented and its possibilities to participate in wavelength multiplexing process have been considered.

Keywords: Volume holographic memories, acousto-optic tunable filters, wavelength multiplexing, resolving power.

1. Introduction

Holographic memory devices are among the most strongly developing kinds of memory, due to its high productivity and parallelism of data recording and access – Ref. 1. In order to improve the holographic memory information characteristics, especially to provide bigger recording density, the volume holographic memory (VHM) devices have been elaborated – Refs. 2-5.

The most precious feature of the VHM devices and systems is ability to record, store, and reconstruct a number of holograms through the same area of the recording medium surface, i.e., the holograms can overlap each other in the recording medium. In order to record, and then to reconstruct the holograms separately, it is necessary to assign different values of some parameter of the reference beam, and further to reconstruct the holograms with the reconstructing beam having the same value of this parameter. Such a procedure is known as multiplexing.

The most common kind of multiplexing is multiplexing by the beam incidence angle. However, there are some other kinds of multiplexing, for example, by light beam wavelength, by shift, by phase coding, and some other kinds.

2. Wavelength multiplexing and its application together with angular multiplexing

The principle of wavelength multiplexing includes recording of many holograms to the same place of the recording medium (for example, photorefractive crystal) – Ref. 6. Each hologram is recorded using light of different wavelength. Of course, this kind of multiplexing means that the hologram recording must be performed with both object and reference beams of the same wavelength but the wavelength must duffer for each hologram recording.

The main problem of such systems realization is to find the suitable laser which could provide the corresponding frequency tuning. Some dye lasers are known in which the light frequency tuning is possible in the range from 370 to 890 nm – Ref. 3. However, in order to provide such a wideband tuning, in is necessary to use many dyes sequentially. In the opposite case the tuning band does not exceed usually value of 10…20 nm. From the other hand, the VHM architecture which includes multiplexing, requires rather powerful laser because the diffraction efficiency of the separate hologram can be rather small in the case if a big set of such holograms has been recorded.

Sometimes, however, the combinations of different kinds of multiplexing can be used. For example, in order to increase the recorded data density, the combination of wavelength and angular multiplexing has been used – Ref. 7. In this system the angular multiplexing degree has been provided about 400, and only 5 wavelengths of light have been used in order to obtain the wavelength multiplexing. The wavelength multiplexing is used here as a kind of rough switching, and angular multiplexing – as fine switching.

The basic configuration of VHM of such type is represented in figure 1. In this system all 200 holograms multiplexed both by angle and by wavelength have been recorded through the same area of the recording medium which represented the $LiNbO_3$ crystal with volume of 1.86 cm^3. According to Ref. 7, the input plane coincides with the output plane of acousto-optic deflector providing the angular multiplexing.

The system schematically shown in fig. 1, was illuminated by light from Ar laser which included modes with wavelengths of 514.5, 501.7, 488.0, 476.5, and 459.7 nm. These light waves were separated and further united back by means of the system of prisms and the set of the shutters. Then the beams, as shown in fig.1, were divided into the object and reference directions, and the holograms were formed in the photorefractive

$LiNbO_3$:Fe crystal. The readout has been performed by the reference beam with the parameters corresponding to each multiplexed hologram, and the output data were registered by CCD array, and further processed by PC.

This VHM system has rather complicated configuration connected with the need to separate and reunite the different light modes of Ar laser. We have proposed the more simple decision of this problem.

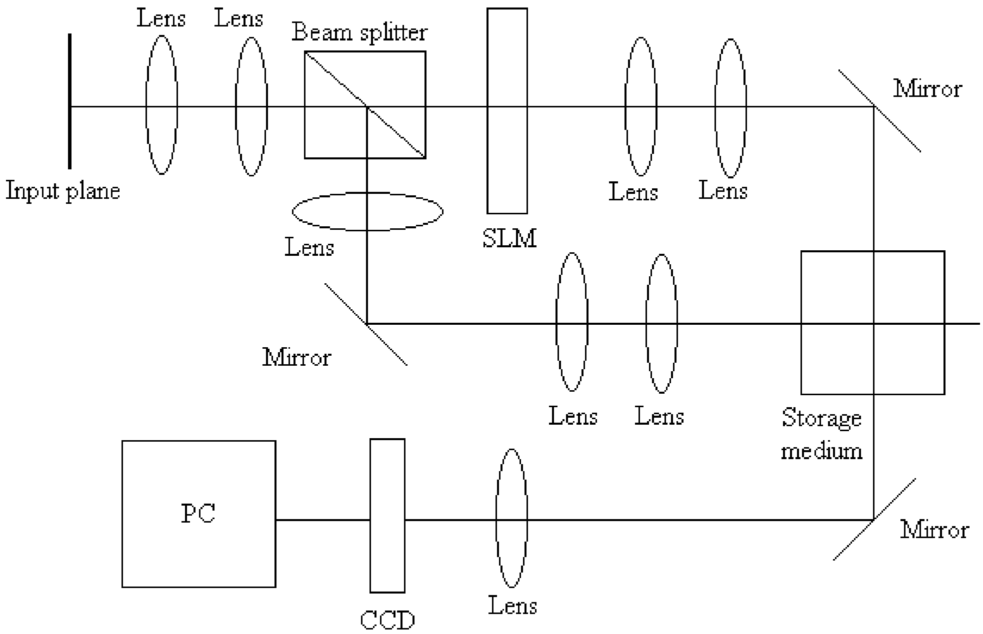

Figure 1. Schematic representation of the VHM system in which the combined angular and wavelength multiplexing has been used

3. Acousto-optic tunable filter application as a wavelength multiplexer

Despite the other acousto-optic devices, acousto-optic tunable filters (AOTF) are not the common devices to be used in holography. Such devices as AOTF usually deal with polychromatic light. However, in the case described in the previous division, it is evident that application of AOTF can simplify the system rather significantly. Let us consider the way to use AOTF in the system studied in Ref. 7. Figure 2 shows the configuration in which AOTF is included in the part of the scheme which must be to the left hand from the input plane shown in fig. 1.

AOTF is established at the output of Ar laser mentioned above. Of course, between the laser and AOTF intermediate optics must be foreseen, which is omitted in fig. 2. These optics provide the necessary light beam cross section form and size. AOTF is fed by the signal which can include five frequencies each of which creates Bragg conditions in the cell of AOTF corresponding to each light mode of Ar laser. The RF source is able to issue these frequencies both sequentially and simultaneously, depending on the required VHM system operation mode.

AOTF selects the necessary laser light mode according to the frequency contained in the input signal. The other light modes do not diffract at the acoustic wave because Bragg conditions are not met for them, and pass the AOTF crystal without diffraction. In order to avoid the undesirable illumination of the system, these undiffracted modes are rejected by the rejection filter.

We have prepared such an AOTF for the laser light mode separation. Its Bragg cell was made with tellurium dioxide single crystal in which shear slow acoustic mode was excited. The piezoelectric crystals of $LiNbO_3$ have been used as transducers for acoustic wave excitation in tellurium dioxide. Due to the crystal axis deviation from [110] crystallographic axis, the propagation direction shift has been provided relatively the normal direction to the piezoelectric transducer plane. Hence, the noncollinear acousto-optic interaction took place.

These samples of AOTF were initially intended for the image processing systems – Ref. 8. However, investigation of their resolving power by the selected light wavelength performed according to the method proposed earlier (Ref. 9) have shown they can be used also for selection of laser light modes even located more closely to each other than those in Ar laser.

The distance between the light modes frequencies in Ar laser varies from 12 to 16 nm. On a level with that the studied AOTF allowed to select frequencies with frequency resolution of 5…7 nm. But the resolving power defined for image processing application must differ from that defined for the laser mode selection for hologram recording and reconstruction, especially for the system with combined hologram multiplexing.

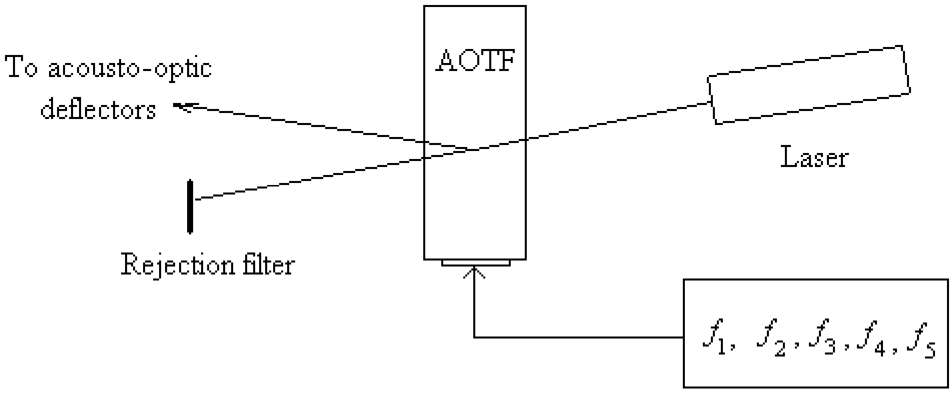

Figure 2. AOTF established in the laser output for different light modes selection.

4. Resolving power criterion for the AOTF – wavelength multiplexer

In order to define AOTF resolving power criterion for AOTF – wavelength multiplexer, we must proceed from the fact that the device operates correctly if it select the necessary mode with admissible level of crosstalks. This level is usually determined by the hologram diffraction efficiency, total degree of multiplexing, and necessary dynamic range of a reconstructed hologram.

Let us suppose that the distance between laser modes in wavelength scale is $\Delta\lambda$ and three modes are located in such way that $\lambda_1 + \Delta\lambda = \lambda_2$ and $\lambda_2 + \Delta\lambda = \lambda_3$, where λ_1, λ_2, λ_3 - wavelengths of adjacent laser modes. Let us also suppose that AOTF selectivity depends on the wavelength mismatch according to Gauss law (this takes place in practice). We also suppose that all modes are of equal intensity. Hence, the light transmission function of AOTF tuned to wavelength λ_2 can be expressed as

$$T(\lambda) = T_0 \exp\,[-(\lambda - \lambda_2)^2/\sigma^2], \quad (1)$$

where T_0 corresponds to Bragg cell diffraction efficiency, and σ is the selectivity function standard deviation. If dependence of each mode intensity on wavelength is close to delta function, it is possible to find the cross talk level I_{ct} which can be expressed as

$$I_{ct} = 2I_0 \exp\,(-\Delta\lambda^2/\sigma^2), \quad (2)$$

where I_0 is intensity of the mode with wavelength λ_2 transmitted by AOTF. If the cross talk level must be N times less than the transmitted mode intensity, so it can be calculated that

$$\Delta\lambda = \sigma\,(\ln 2N)^{1/2}. \quad (3)$$

Expression (3) represents the relationship describing the resolving power criterion by light wavelength for AOTF as wavelength multiplexer in VHM system. This can be interpreted by the following way: the modes which wavelengths are located at distance of $\Delta\lambda$ from each other can be resolved by AOTF with Gaussian selectivity with standard deviation of σ if the condition

$$\sigma \le \Delta\lambda\,(\ln 2N)^{-1/2}. \quad (4)$$

Note that this expression can be considered correct only in the case if the selected laser modes are narrow enough. Hence, this criterion can appear inapplicable for some semiconductor lasers. But the lasers with wide light modes sometimes cannot be used for hologram recording due to their low coherence.

5. Conclusion

We have proposed the way to improve the VHM system described by Campbell and Yen [7] by means of AOTF application. We have also developed the AOTF wavelength resolving power criterion for this case. Despite of rather limited application of the proposed scheme, it seems that the approach stated above can be used also for some other VHM configurations, and the resolving power criterion can be expanded for different AOTF applications dealing with selection of narrow spectral lines.

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