High resolution and compact slit-less spectrometer using spherical beam volume holograms

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Abstract: We present compact slit-less spectrometers using spherical beam holograms with resolution close to 1nm using thick holographic materials. The spectrum estimations of unknown light sources are used to demonstrate the performance of these slit-less spectrometers.

OCIS Codes: (090.7330) Volume holographic gratings; (300.6300) Spectroscopy, Fourier transform, (999.9999) Spherical beam holograms.

Compact and sensitive spectrometers are of high utility in biological and environmental sensing. In a conventional spectrometer, a collimator (usually composed of a narrow slit and a lens), a grating, a collector (usually a lens), and a CCD (or a detector array) are essential to separate different wavelength channels. However, this system is inefficient especially for detection of a diffuse source because most of the input power is blocked by the collimator. Besides, since too many elements are required, this system is bulky and usually sensitive to alignment. To make the spectrometer more compact and potentially more efficient, we recently presented for the first time a new class of spectrometers named Fourier-transform volume holographic spectrometer [1]. In this new spectrometer, the collimator and the grating are integrated into a volume hologram so that only a hologram, a lens, and a CCD are required. The hologram, which is the key element of this spectrometer, can be as simple as a single spherical beam volume hologram (SBVH) formed by the interference pattern of a plane wave and a spherical beam.

The SBVH is recorded by the interference of a plane wave and a spherical beam originated from a point source as shown in Figure 1(a) using a solid-state laser at wavelength $\lambda = 532$ nm. More details about the configuration and the parameters of the recording setup are specified in the caption of Figure 1. The SBVH is then put into the Fourier-transform volume holographic spectrometer system as shown in Figure 1(b) for evaluation.

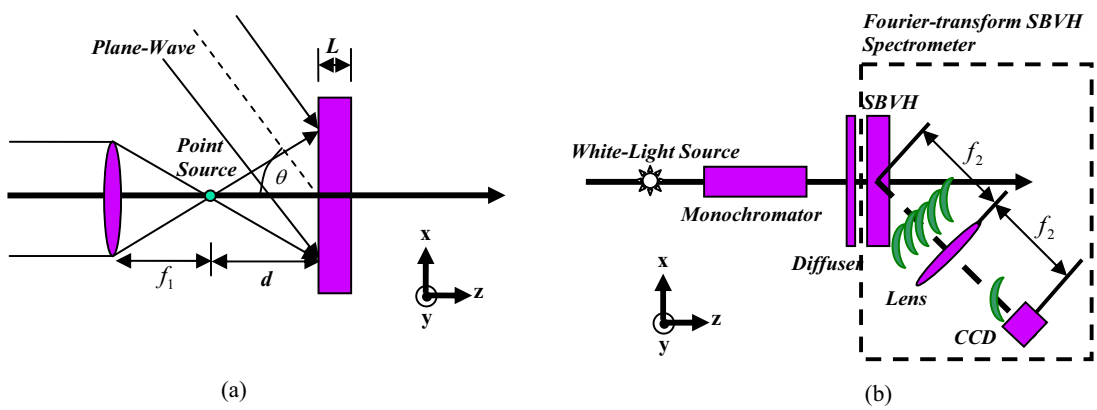

Fig. 1. The general schematics of (a) the recording setup for a SBVH and (b) the Fourier-transform volume holographic spectrometer. The recording material is a photopolymer with thickness L. The spherical beam is formed by focusing a plane wave with a lens with focal length f_1. The distance between the hologram and the point source is d. The angle between the plane wave direction and normal to the medium is θ. The focal length of the Fourier transforming lens in the reading setup is f_2. These parameters are varied based on the requirements of different experiments. A rotating diffuser can be added into the reading system to generate a spatially incoherent incident beam as shown in (b).

To show the wavelength separation at the output of the proposed spectrometer, we used the experimental setup in Figure 1(b) and scanned the input wavelength from $\lambda = 482$ nm to $\lambda = 587$ nm with 5 nm spacing using the monochromator. The SBVH used in this experiment was recorded in a 100-μm-thick photopolymer. The output intensity for each incident wavelength was captured by the CCD. The normalized output intensity (i.e., the output intensity divided by the input intensity) versus the location in the horizontal axis on the CCD is show in Figure 2(a).

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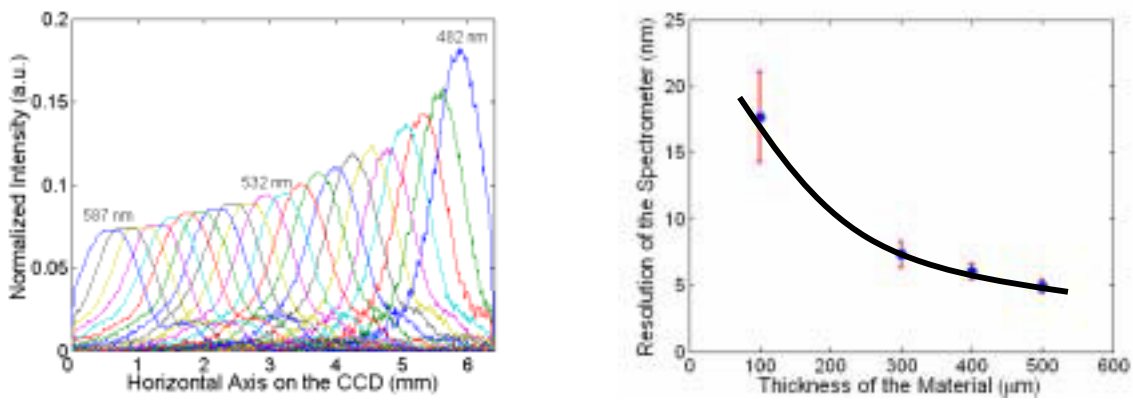
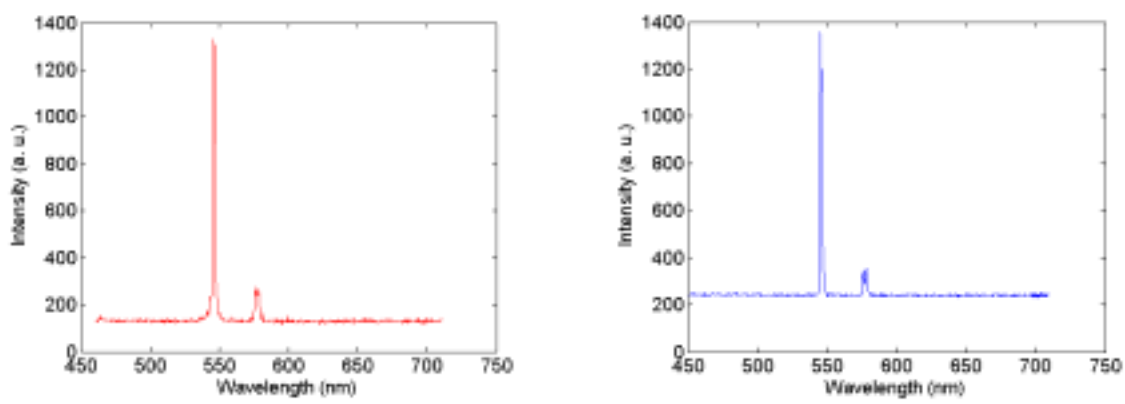
Each curve in Figure 2(a) corresponds to one incident wavelength. Figure 2(a) clearly shows that the output spatial intensity pattern is only a function of the incident wavelength even under highly diffuse light illumination.



(a) (b)

Fig. 2. (a) Normalized intensity versus the location along the horizontal axis on the CCD in Figure 1(b) for the SBVH described in the text. The hologram is read by a diffuse light (using the rotating diffuser) with single wavelength at each time. The reading wavelength is scanned from $\lambda = 482\text{nm}$ (the far right curve) to $\lambda = 587\text{nm}$ (the far left curve) with 5nm spacing. (b) The effect of the thickness of the material on the resolution of the spectrometer.

From the Bragg selectivity of volume holograms we know that recording a hologram in a thicker material leads to a better wavelength selectivity and, therefore, a better resolution for this spectrometer [2]. Figure 2(b) shows the experimental data of the relation between the resolution and the thickness of the material. It is indicated that the better resolution can be achieved by using thicker materials. Therefore, as a simple improvement, a 2-mm-thick holographic material is used to record the SBVH. To obtain better optical quality, we used a $LiNbO_3$ crystal instead of photopolymer to perform the spectrum estimation experiment. Figure 3 shows an example of the spectrum estimation for a Hg-Ar calibration lamp using our slit-less spectrometer and a commercial Ocean Optics spectrometer. In Figure 3, two close peaks at 577nm and 579nm are nearly detected in both cases, which indicate that the resolution for both spectrometers is better than 2nm.



(a) (b)

Fig. 3. Spectrum estimation for a Hg-Ar lamp using (a) slitless spectrometer and (b) Ocean Optics USB 2000. The two peaks at 577 nm and 579 nm are nearly detected in both cases.

Further improvement of the resolution will be addressed and the spectrum estimation for more sophisticated light sources will be demonstrated in this talk. Besides, the resolution performance for more compact lens-less holographic spectrometer [3] will also be discussed.

References

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