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Final Report
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"Spectral and Angle Selective Holographic Devices"

Submitted to: European Office of Aerospace Research and Development

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One of the most attractive properties of volume holograms is their high diffraction efficiency (close to 100%). It is well known also that volume holograms possess very high angular and spectral selectivity. In some cases such highly selective holograms can find wide applications, for instance in three-dimensional imaging, a variety of diffraction optical elements, holographic storage, systems for laser monitoring, etc. Although in some cases so high selectivity is undesirable, and it is necessary to avoid it.

During the contractual effort we studied selective properties of volume holograms in two limiting cases: (1) very thin and most possible spectrally *unselective* volume holograms to be used as broadband solar energy concentrators and (2) very thick and most possible *selective* volume holograms to be used as filters for laser beams, spatial or spectral.

Solar concentrators are required to exhibit high diffraction efficiency in a wide spectral band. So far as high diffraction efficiency can be obtained if using a thick hologram, and low spectral selectivity is a property of thin holograms, the solution of the problem can be the most possible thin volume hologram. We have shown ([1,2]) that a transmission volume hologram with more than 90% diffraction efficiency can be recorded in the layers 2-3 micrometers thick. Such a hologram works with high efficiency in the spectral range from UV to near IR. The optimal recording geometry has been found and geometrical parameters of the spectrum obtained were analysed. It was shown that cooling requirements are considerably lower for the photovoltaic system based on holographic concentrators, it can operate even without heatsink.

On the contrary, spectral or spatial filters of laser radiation must exhibit very high selectivity. Basing on the Kogelnik's coupled waves theory we considered requirements on the thickness of holographic medium and its resolution ability to record selective elements with reasonable characteristics: 1 millirad for the angular selectivity and 0.1 nm for the spectral selectivity for both types of holograms (reflective and transmissive) [3,4]. It was shown that to record an angular selector with the bandwidth of angular selectivity contour of 1 mrad, it is reasonable to use transmissive holograms in the range of spatial frequencies more than 1500 lines per mm. On the contrary, in general, reflective holograms are more suitable for recording of spectral selectors with the selectivity of about 0.1 nm, especially in the frequency range less than 3500 1/mm. In both the cases the holographic material to be used for the recording of elements that are of practical interest must be about millimeter thick or more.

Standard holographic materials can not be used for recording of so thick holograms. The main problem associated with the manufacturing of such holograms is in preparing of the photosensitive materials nearly without shrinkage and inhomogeneities. We have analysed ([5]) an influence of the following parameters on the image quality and selectivity properties: change of the mean refractive index during the postexposure development; shrinkage existence; as well as non-uniformities of these parameters in the grating depth. It was shown that even small change of the mean refractive index and shrinkage (of about 0.003) lead to extremely large distortions in the reconstructed image both in phase and amplitude that cause losses in the reconstructed image resolution. The non-uniformities in depth of

the grating power, mean refractive index and shrinkage affect mainly the shape of the selectivity contour and can lead to its broadening and asymmetry. The latter is important to take into account, for example, when calculating the information capacity in systems of holographic storage based on volume holograms. The analysis of materials suitable for recording of so thick holograms has been made in [3,5].

We proposed to use the high angular selectivity of volume holograms to create the new type of laser beam filter. This filter consists of two transmissive volume holograms each of which carries out the filtration of spatial frequencies in one direction and possesses the angular selectivity of about 1 milliradian. It has been found that to keep the polarization condition of the radiation to be filtered, as well as to obtain reproducibility of parameters and compactness, the holographic filter has to consist of two identical symmetric gratings with mutually perpendicular grating vectors and parallel surfaces. Theoretical estimations ([6]) show that such a compound filter can have high overall diffraction efficiency (90% for "pure" light) and at the same time full angular selectivity (2D) of less than 1 millirad. In our experiments ([6]) we used two materials: porous glass and photopolymer with diffusion amplification. We studied maximal magnitudes of diffraction efficiency and shapes of angular selectivity contours of 3D gratings recorded in these materials for their thicknesses of 1-2 mm and spatial frequencies of 900-2200 mm⁻¹. We obtained holographic gratings with the diffraction efficiency at 633 nm of 80-97%. The bandwidths of angular selectivity contours of these gratings are (0.5 - 2)*10⁻³ rad.

Thus, during one year of the contractual effort we have performed:

1. Analysis of selective properties of *thick* volume holograms (both spectral and angular) depending upon hologram parameters (layer thickness, spatial frequency of the recorded grating) for reflective and transmissive holograms.
2. Analysis of spectral selectivity of *thin* volume transmissive holograms depending upon hologram thickness and recording geometry.
3. Analysis of new holographic media suitable for recording of volume holograms several mm thick.
4. Development of the best architecture for the holographic angular selector of laser radiation.
5. Development of the best architecture for the holographic concentrator of solar energy.
6. Recording of holographic angular selectors in two materials: porous glass and photopolymer with diffusion amplification. Analysis of their characteristics depending upon the grating parameters.

The results obtained were presented at the two conferences: Fifth Annual Advanced Technology Workshop, ATW'96 USA-Europe, August 6-9, 1996, Bedford, MA, USA [3]; 50th Annual Conference of the Society for Imaging Science and Technology, May 18-23, 1997, Boston, MA, USA. Two papers are accepted for presentation at the EOS Topical Meeting on Diffractive Optics, July 7-9, 1997, Savonlinna, Finland [1,4]. Three papers are accepted for publication in technical journals ([2, 5, 6]).

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