Production of narrowband holographic selectors for SLR

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Abstract

The article reports about organization of full serial production cycle for the narrowband holographic selectors for laser remote sensing purposes particularly for SLR. The main stages of production cycle are discussed, the photos of main facilities are represented, characteristics of first serial samples are given and ways for further development are analyzed.

Introduction

Achievement of high efficiency of the laser locator is always trade off between a spectral selectivity of the receiving channel and its energetic transmittance. Therefore a narrowband spectral selector becomes an integral part of any device. Intensive use of the SLR systems during last decade has laid down the requirements to them:

- ✓ Narrow transmittance band (about 100 pm)
- ✓ High energetic efficiency (85-90%)
- ✓ High time stability
- ✓ Low temperature drift
- ✓ Reasonable cost

Today the following optical elements meet most the requirements:

- ✓ Interference filter
- ✓ Atomic filter
- ✓ Faraday's filter
- ✓ Holographic selector

The latter, in our opinion, not only possesses excellent selective properties but also suitable for serial production.

Basic relations

The great technical potential of 3D holography has been attracting attention since its very early days; the unique spectral selectivity of thick holograms has given an impetus for many potential applications.

Optical layout of the recording and reconstruction (use) of the narrowband holographic selector is shown in Fig.1. The reflection geometry makes it possible to avoid undesirable narrow angular selectivity of a spectrally selective hologram.

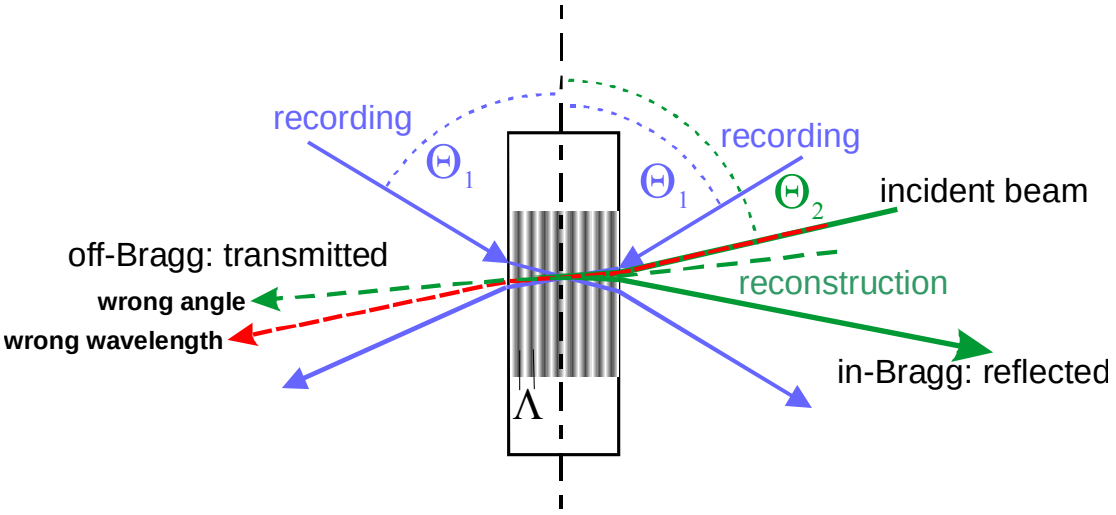

Figure 1. Optical layout of the recording and reconstruction of the holographic selector

The relation between a holographic grating period, beam-path geometry and the half-width of the spectral selectivity contour may be expressed as follows:

$$\Delta\lambda \approx \frac{6n \cdot \Lambda^2 \cdot \sin\Theta_2}{\pi \cdot d}.$$

where Λ is the grating period, Θ_2– incidence angle of the reconstructing beam in the material, n and d – refractive index and thickness of the photo-sensitive medium, respectively. Obviously that appropriate choose of the parameters may give theoretically any value of the spectral selectivity. For instance, to obtain 100 pm bandwidth at λ= 532 nm and Θ_2= 2.5^0 the grating should be 1 mm thick.

The univocal relation between spectral selectivity and angular one for the holographic selector:

$$\delta\lambda(\Theta) \approx \frac{\lambda}{n^2}\left(\left(\frac{\pi}{2} - \Theta_2\right) \cdot \Theta + \frac{\Theta^2}{4}\right)$$

provides a convenient opportunity to substitute the measurements of spectral selectivity by angular measurements.

Manufacturing stages and their implementation

The main stages of manufacturing of holographic selector are shown in Fig. 2:

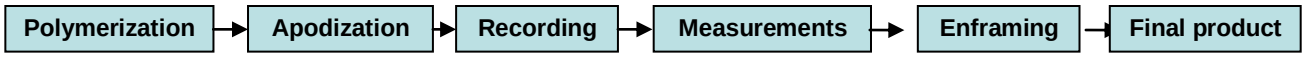

Figure 2. Main stages of manufacturing holographic selector

Phenanthrenequinone (PQ)-doped Poly(methyl methacrylate) remains at present the most realistic candidate as the material for thick holographic selective optics possessing necessary time and thermal stability characteristics, due to ability of PQ to bind to polymer chains under exposure and the effect of elimination of complementary gratings. Since their invention (Veniaminov, 1991), the PQ-based materials have served in many examples of selective holographic elements (e.g. Ludman, 1997, Mahilny, 2006, Russo, 2007), including the spectral selectors for laser detection and ranging (Popov, 2000); now we report the establishment of systematic production.

The material is manufactured by radical bulk polymerization of methyl methacrylate with PQ and radical initiator in inert atmosphere under elevated pressure and temperature following the schedule optimized for optical quality, maximal conversion to polymer and minimal mechanical stresses. The view of the bulk polymerization facility is shown in Fig. 3:

Figure 3. The facility for production of photosensitive material by polymerization method

It is known (Kogelnik, 1969) that the selectivity contours of 3D holograms recorded uniform in the material depth demonstrate multiple side-maxima whose relative intensity grows with diffraction efficiency, thus broadening the apparent selectivity. However, using a bell-shaped, e.g. Gaussian, distribution of the grating strength leads to dramatic suppression of the side-maxima (apodization). Such a distribution can be achieved by recording a hologram in the material with spatially non-uniform concentration that in turn can be created by bleaching the light-sensitive centers predominantly in the superficial layers in the course of pre-exposure incoherent illumination (Fig. 4) whose spectrum and duration controls the parameters of the resulting distribution, hence the selective properties (Popov, 1994).

Recording of the hologram is a principal stage of the narrowband holographic selector manufacturing. Optical layout of the process based on Zender-Mach interferometer is represented in Fig. 5. Argon-ion CW laser Spectra Physics® model 2060 is used as a light source. Special care has to be taken to provide high mechanical and thermal stability.

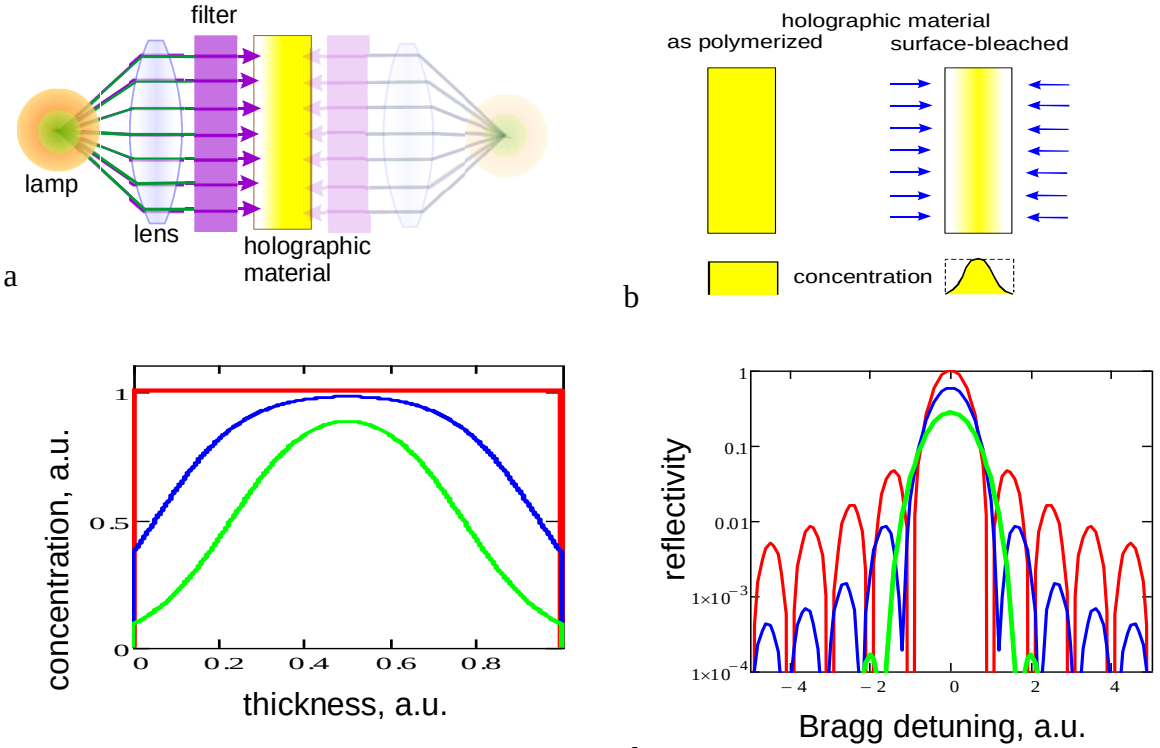

Figure 4. Photoapodization: schematic representation of pre-exposure treatment (a, b), light-sensitive centers distribution at different depths of apodizing treatment (c) and corresponding selective response functions of holographic gratings recorded in thus "apodized" material (d)

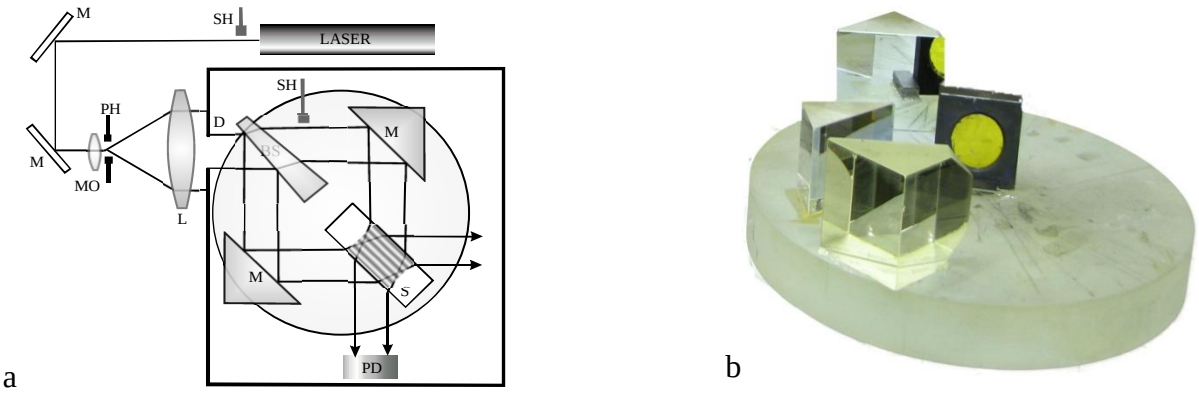

Figure 5. Optical layout (a) and general view (b) of the interferometer used for the hologram recording

The duration of the recording process is about 1 hour. Fig. 6 illustrates a general view at the recording facility during its final pre-exposure adjustment. After the exposure, the hologram should be kept at moderately elevated temperature during a few hours for self-development, and then fixed by uniform incoherent illumination.

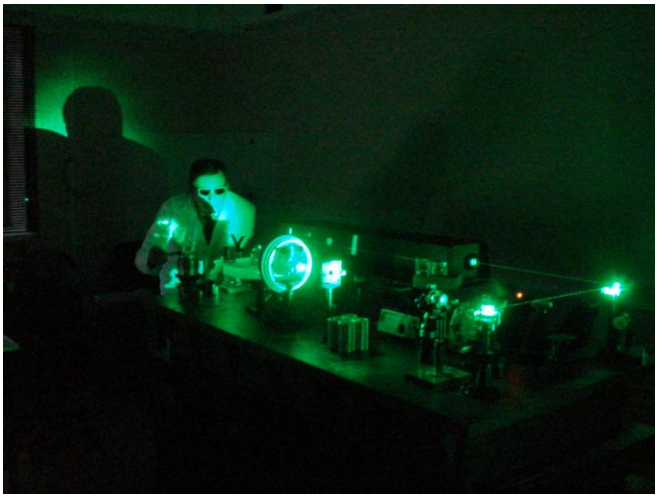

Figure 6. General view of the recording facility

Measurements of characteristics of the holographic selector take place in the next stage. Optical arrangement of the angular selectivity measurement is shown in Fig. 7. The light emitted by stabilized CW DPSS YAG:Nd^{+3} laser (532 nm) collimated by the lenses L and MO (micro objective) with the pinhole PH hits the sample S with a holographic grating in it installed on the top of the precise rotary table RT. The light beams diffracted back from the grating and passing through it are projected by two objective lenses OL to the photodetectors PD. The electronic unit controls the stepping motor of RT and transfers the signals from PD to the computer. The angular resolution of RT is 3.5×10^{-5} radians that corresponds to 0.35 pm spectral resolution.

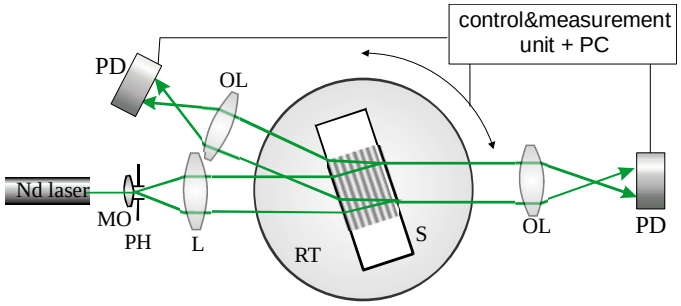

Figure 7. Optical arrangement of the angular selectivity measurement: Nd laser, collimator consisting of lenses, rotary table RT , objective lenses OL collecting transmitted and diffracted light on the two photodetectors PD, and the electronic unit responsible for controlling the stepping motor, signal acquisition and its transfer to the computer.

At the final stage of the production cycle holographic selector is placed into sealed-off container between two AR-coated windows in order to prevent the material from contacts with a humid atmosphere and thus keep constant characteristics at different application conditions. A ready-to-use narrowband holographic selector and its typical spectral curve i.e. a dependence of the reflectance coefficient upon wavelength are shown in Figs. 8 a and b, respectively:

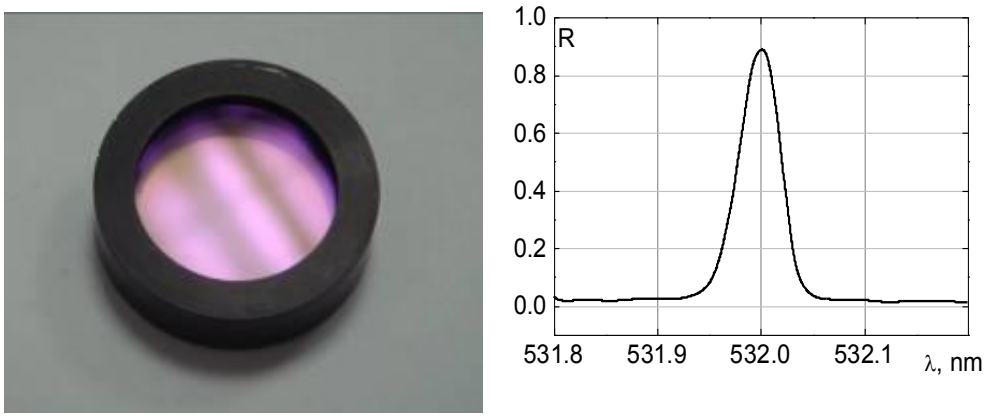

Figure 8. Narrowband holographic selector (a) and its typical spectral curve (b)

As a result the narrowband holographic selector possesses the following characteristics:

- ✓ spectral selectivity $\Delta\lambda \sim 100$ pm
- ✓ maximal selective reflectivity ~ 90%
- ✓ spectral range: visible and NIR regions (typically $\lambda = 532$ nm)
- ✓ thermal wavelength shift ~5 pm/K
- ✓ lifetime: years (at moderate temperatures < 60^0C)
- ✓ selective reflection angle $5 \div 7^0$
- ✓ angular selectivity $\Delta\theta = 0.5^0$

Current status and prospects of the work

Lifetime of the selector i.e. stability of the characteristics in time is one of its most important features. The first prototypes produced in 1980s (Sukhanov, 1984) based on reoxan proved useful but revealed relatively low values of both diffraction efficiency and lifetime. (see Fig. 9).

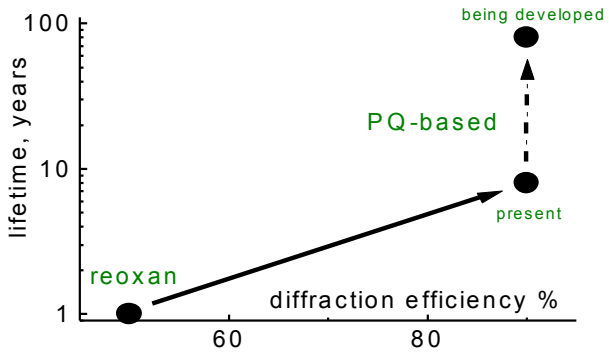

Figure 9. The diagram illustrates a current status of the development of the narrowband holographic selectors

Using phenanthrenequinone doped polymethyl methacrylate has substantially improved these figures. The holographic elements produced today keep their properties for several years and their diffraction efficiency reaches a practical limit. The major remaining problem consists in slow tiny diffraction angle drift that is often considered negligible but may nevertheless lead to some deviation of grating parameters from their initial values. Further progress may go different ways. For instance, fine mechanical or thermal adjustment of the incidence angle can be provided with the help of diffracted light intensity feedback. Alternatively, the material can be enforced with a microporous network or microscopic inert particles. Our main efforts are concentrated in finding stable material compositions least sensitive to changes rather than compensating the effects of such changes.

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