Refractive index change calculation

Refractive index change is calculated by the formula below:

$$n = \frac{\varphi\lambda}{2\pi h}. \quad (1)$$

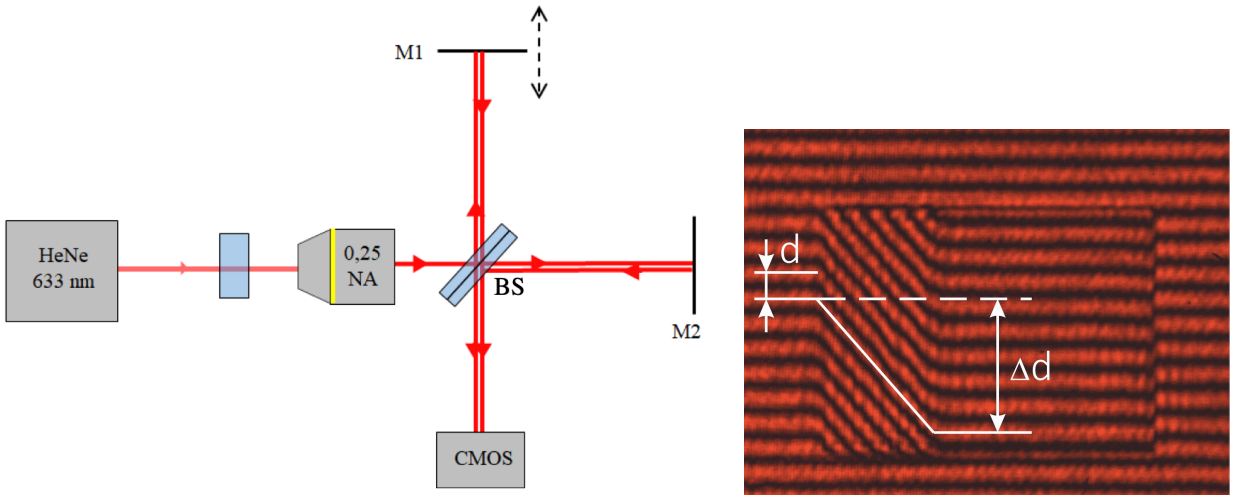
- φ - phase shift found by combining Michelson interferometer [1] and MATLAB analysis.
- λ - wavelength of the laser beam (633 nm in case of HeNe laser).
- h – structure height or thickness, measured by the optical microscope.

Phase shift is found by the formula:

$$\varphi = \frac{\Delta d}{d} \cdot 2\pi. \quad (2)$$

- Δd – interference line shift (see Fig 1. b).
- d – interference line period (see Fig 1. b).

The structure is made from separate layers written by the femtosecond laser irradiation inside fused silica volume. This irradiation changes the refractive index of the glass, and this change can be seen with interferometer as the difference between phases or the difference between interference lines.



a) b)

Fig 1. a) Phase shift measurement schema with Michelson interferometer. b) Interference line shift due to increased refractive index in the structure. [1].

In Fig 1. HeNe laser beam goes through the sample to the 0.25 NA objective lens, where the view is enlarged and then with beam splitter (BS) is split into the beam which reflects from the mirror M1 and the beam which reflects from the mirror M2. Interfered beam is captured with the Basler A2500 14gc (5 Mpx) camera.

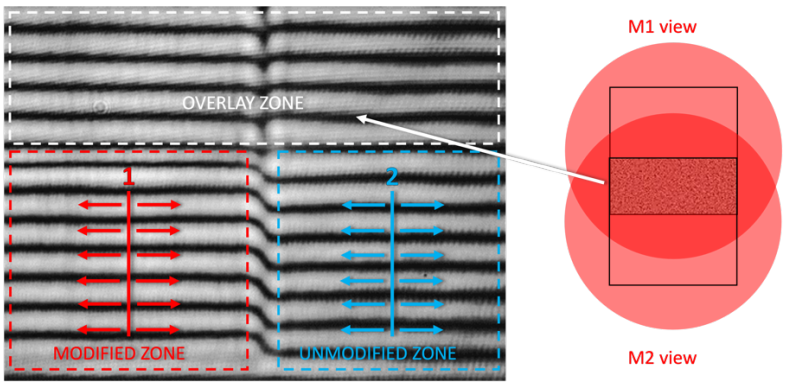
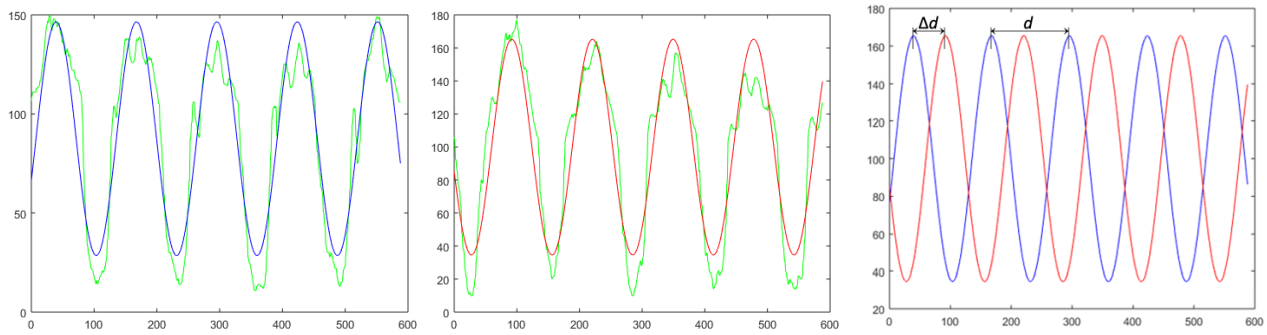


Fig 2. Image analysis with MATLAB by drawing two lines: 1 – modified zone, 2 – unmodified zone.

Image captured with the camera is analyzed with the MATLAB. The method includes intensity determination and approximation with sine function. In the image two lines are drawn in such way that they cross the interference lines to give sinusoidal intensity distribution (Fig 2.). First line corresponds to the modified zone (Fig 3. a) and the second one – unmodified zone (Fig 3. b). To increase the precision of this method multiple areas near the drawn lines are analysed and averaged (left and right arrows shown in Fig 2.). There is also posibility to measure the picture several times (code runs over again) and get even more precise result.



a) b) c)

Fig 3. Intensity distributions with the sine approximations: a) first line (modified zone); b) second line (unmodified zone); c) first and second line approximations put together with the average amplitude and period.

Literature

[1] A. Žukauskas, I. Maltulaitienė, D. Paipulas, M. Malinauskas, R. Gadonas, Tuning the refractive index in 3D direct laser writing lithography: towards GRIN microoptics, Laser Photonics, **9**(6), 706-712 (2015).