DIFFRACTION APODIZING FILTER OF FOCUSED LASER BEAM

A.G. Sedukhin1, V. P. Korolkov1*, A.G. Poleshchuk1, and N. Yu. Nikanorov2

1*Institute of Automation and Electrometry, Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russia
2Novosibirsk Instrument Making Plant, Novosibirsk, Russia

The problems of a high-contrast focusing of laser beams arise in very numerous applications. As is often accepted, in the simplified case of an ideal one-beam stigmatic focusing, in the focal plane of a focusing lens it would be well to form a small laser spot approaching to the Dirac delta function, while all the parasitic light beyond that spot must be eliminated. For example, such high-contrast laser focusing might be desirable in systems of direct laser writing, especially, if using the multi-pass laser scanning for recording complex high-resolution patterns together with using linear thin-film recording media like photoreists. In this case, one can avoid the harmful accumulation of light energy in the unexposed areas near the edges of the exposed ones and to enhance the contrast of a resulting pattern. The same would be of importance in systems of one-step projection laser lithography, where each point of the recorded pattern is formed by the respective point spread function of a photolithographic lens. To improve the quality of laser beams in the above systems, in the present work, a novel diffraction apodizing filter is proposed and studied. The elaboration of the principle of operation of such filter was the first goal of this work. It is explained in Fig. 1.

The second goal of the work was to find the optimum profile of the amplitude transmittance of the filter. Here, it is supposed that the focusing lens has a moderate numerical aperture, enabling one to use the scalar paraxial approximation of the diffraction theory. Besides, this lens is fully corrected for aberrations and has a perfect phase transmittance. So, the only free parameter is the amplitude transmittance of the lens. As was shown in the earlier investigations, one of the best approximations to the mentioned ideal focused laser spot is the amplitude distribution described by the prolate spheroidal wave function of zero order. This function is very close, in practice, to the distribution at the waist of a fundamental Gaussian beam. However, in this work, we have found that the tails of the prolate and Gaussian functions are not optimum in the sense of the trade-off between obtaining the small levels of the first parasitic side lobes of the laser spot and the size of the main central lobe. The proposed S-shaped radial profile of the amplitude transmittance is shown to provide better characteristics. In the mean radii, the amplitude transmittance is approximated by a linear decaying function (close to the Gaussian function, in order to suppress the edge diffracted wave [2]), whereas near the very boundary of the lens aperture the transmittance corresponds to the inverse apodization. The last feature promotes to enhance the resolution and the light efficiency, while keeping almost the same level of the first side lobe.

The filter was numerically simulated, fabricated in the form of a circular glass plate with a thin-film chromium mask, and experimentally tested for a particular case of the range of wavelengths between 400 nm and 800 nm, with diameter of the filter being equal to 100 mm. A precision computer-controlled laser photoplotter was used for fabrication of the filter. As was found, if one assumes the uniform input illumination and the 10-fold suppression of the intensity of the first lobe of the point spread function, the filter increases the diameter of the first lobe (at zero intensity) by about 20 % and decreases the total light efficiency to a level of about 32 %. The experimental results are in agreement with theory.

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References