DOI: 10.61782/fa.2025.0094

FORUM ACUSTICUM
EURONOISE 2025

ACOUSTO-OPTIC SPATIAL FREQUENCY FILTER WITH PHASE CONTROL FOR RECONFIGURABLE DARK OPTICAL TRAPS

Vladimir Ya. Molchanov[1]* **Alexander I. Chizhikov**[1] **Dmitry V. Obydennov**[1]
Konstantin B. Yushkov[1]
[1] Acousto-Optical Research Center, University MISIS, 119049 Moscow, Russia

ABSTRACT

We have developed an original acousto-optic spatial filter (AOSF) of laser beam angular frequencies for dynamically forming cylindrical laser beams with two walls advanced optical trap configurations. To expand the functionality of AOSFs, independent phase control should be added to frequency control, thereby transforming the filter's two-dimensional transfer function (2DTF) from a function of one variable into a function of two independent variables. The 2DTF is controlled by a variable phase of radio-frequency signal at a constant frequency. The peculiarity of the AOSF with phase control is based on the tilt of the acoustic wave front, which compensates for the asymmetry of the two-dimensional transfer function and makes it possible to create pairs of concentric intensity maxima separated by a dark region. An experimental AOSF on paratellurite has been designed and fabricated. This modification of the filter's annular 2DTF has made it possible for the first time to create double cylindrical beams ("thermos beams") that have direct application for optical trapping and microparticle manipulation. This configuration of the laser potential is in demand in dark optical traps, in which resonant particles are repulsed by the laser field and their trapping occurs in areas with minimum field intensity.

Keywords: *acousto-optics, laser beam shaping, optical trapping*

**Corresponding author*: *v.ya.molchanov@gmail.com.*

1. METHODS

Acousto-optic filters are tunable photonic devices based on anisotropic Bragg diffraction, which are used in spectroscopy, hyperspectral imaging, phase imaging, femtosecond pulse shaping, and laser beam shaping (LBS). The latter application utilizes angular dependence of phase matching, which enables direct filtering of the angular spectrum. Accurate analysis of the AOSF's two-dimensional transfer function can be performed using the curvature tensor of the acousto-optic crystal's refractive index surface [1].

In this work, we report design and fabrication of two AOSF prototypes and their commissioning in LBS systems and optical traps. The basic setup for bottle beam generation is shown in Fig. 1. A laser beam is focused onto the AOSF so that different components of its angular spectrum are diffracted with different efficiencies. The diffracted beam (p-polarization) is polarized orthogonally to the input one (s-polarization), and the first diffraction order is selected by a polarizer at the AOSF output. Relay optics is used for scaling the beam size, and the second Fourier lens converts a conical beam into a bottle beam in its back focal plane.

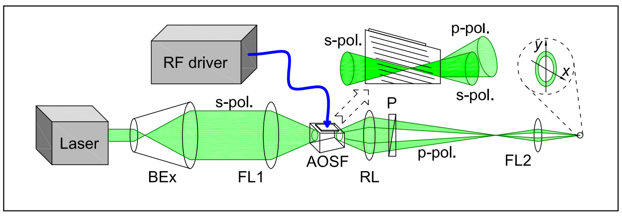

Figure 1. Schematic LBS setup based on an AOSF: BEx — beam expander; FL1, FL2 — Fourier lenses; RL – relay lens; P — polarizer.

The AOSF of configuration #1 was a single-transducer AOSF, which was driven by a radio-frequency (RF) arbitrary waveform generator either in single-frequency or in multi-frequency mode. This AOSF was commissioned with monochromatic radiation at the wavelength of 532 nm and femtosecond radiation at the wavelength near 800 nm. The AOSF of configuration #2 was a dual-transducer AOSF, which was driven by a two channel RF generator with programmable phase delay between the channels [2].

2. RESULTS

Various LBS modes are demonstrated in Fig. 2. Simple annular beam shaping is obtained with monochromatic light and single-frequency RF signal [3]. The phase matching locus is a ring whose radius changes with ultrasound frequency, Fig. 2 (a), that allows creating dynamic annular traps for dielectric particles. In the multi-frequency operation mode, different components of the laser beam's angular spectrum can be diffracted simultaneously with different efficiencies that enables beam profile tailoring. A flat-top beam obtained from a Gaussian beam is shown in Fig. 2 (b). In the case of multi-wavelength laser beam, each spectral component can be controlled independently. Fig. 2 (c) shows a two-color beam obtained from a femtosecond Ti:sapphire laser [4]. The central spot has the wavelength of 800 nm and the outer ring of the laser field has the wavelength of 790 nm.

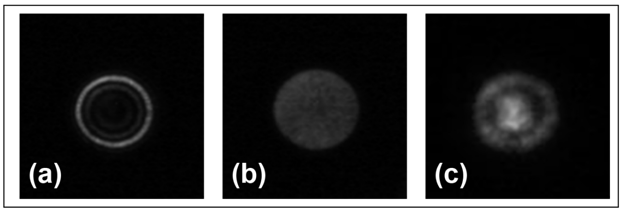

Figure 2. Experimental measurement of laser field distributions at the AOSF #1 output: (a) annular beam shaping of monochromatic light; (b) flat-top beam shaping at multifrequency AOSF operation; (c) multi-color femtosecond beam shaping by AOSF.

Figure 3 demonstrates operation of the phase-controlled AOSF #2 [2]. The RF signal in this case has two independent parameters, the frequency and the phase delay between two channels, which are both used to adjust the transfer function parameters. Owing to the effect of acoustic beam steering, splitting of the transfer function can be achieved. Two-dimensional transfer functions of this type can be used for creating dark optical traps, i.e. volumes with low laser beam intensity enclosed within volumes with higher intensity.

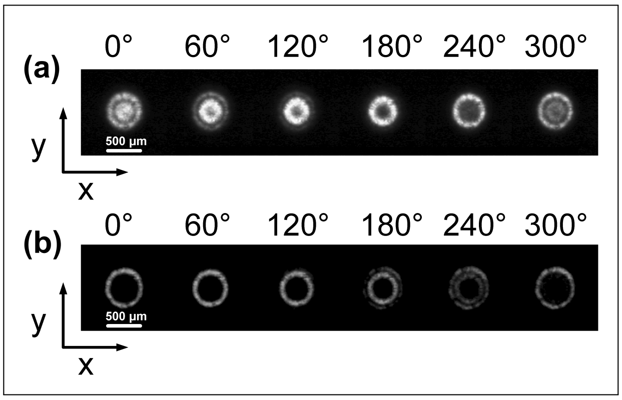

Figure 3. Tunable double-bottle-beam generation with the AOSF #2: (a) dark bottle beam mode; (b) thermos beam having dual cylindrical structure.

3. FUNDING

The research was supported by the Russian Science Foundation under project 20-12-00348.

4. REFERENCES

[1] K.B. Yushkov and N.F. Naumenko, "Optical beam diffraction tensor in birefringent crystals," *Journal of Optics*, vol. 23, no. 9, p. 095602, 2021.

[2] K.B. Yushkov, A.I. Chizhikov, D.V. Obydennov, and V.Ya. Molchanov, "Phase-tuned acousto-optic spatial filter," *Optics Letters*, vol. 49, no. 14, pp. 3866–3869, 2024.

[3] D.V. Obydennov, K.B. Yushkov, and V.Ya. Molchanov, "Ring-shaped optical trap based on acousto-optic tunable spatial filter," *Optics Letters*, vol. 46, no. 18, pp. 4494–4497, 2021.

[4] D.V. Obydennov, K.B. Yushkov, and V.Ya. Molchanov, "Independent multicolored bottle beam generation using acousto-optic spatial shaping of a femtosecond laser beam," *Optics Letters*, vol. 48, no. 20, pp. 5320–5323, 2023.