Acousto-optic devices for high-power laser radiation on KGW crystal

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Abstract. Acousto-optic (AO) devices are widely used in technology to control the characteristics of optical radiation, for example, to modulate amplitude (AO modulators), to deflect light propagation (AO deflectors), either for spectral analysis (AO filters). The main advantages of AO devices are arbitrary spectral and spatial addressing, higher resolution, compactness, efficiency, the absence of moving parts (and as a result - resistance to vibrations), programmability.

1. Introduction

Any AO device usually consists of a single crystal with specific physical properties, where the transmitted optical radiation diffracting on acoustic wave, generated by piezoelectric transducer. With extension of laser technologies, for example, prevailing uses of diode pumping, the variety of high-power sources is growing, which increases the demand for devices to control high-power laser radiation. The acoustical, optical, and photo elastic properties of biaxial crystals of the potassium-rare-earth tungstate family, especially of the potassium-gadolinium tungstate $KGd(WO_4)_2$ (short: KGW) were studied for the first time [1]. It has been demonstrated for the first time that their AO figure of merit M_2 is comparable with that of $LiNbO_3$ and better than M_2 of SiO_2. Moreover KGW crystal has monoclinic structure, transparent in visible and infra-red ranges (0.4-5.5 μm), has significant anisotropy and optically biaxial. Also KGW is a well-known laser material with a very high threshold of laser damage: up to 180 GW/cm^2 for τ = 20 ns pulses [2].
These facts open new potentials in development of optical functional devices. First of all, basic AO devices (modulators, deflectors, tunable filters) made of those materials are able to withstand high power laser radiation, which is very important for laser industrial applications. For example, acousto-optic (AO) mode lockers for high power lasers are usually made of α-SiO_2, so they require a cooling system due to high acoustic power supplied. The laser crystal KGW do not need cooling as it has a higher acousto-optical efficiency. Secondly, some kind of hybrid devices can be designed, which combine laser and acousto-optic properties and provide light generation and light operation on the same crystal element.
In this paper we present three AO devices based on the KGW crystals: polarization-insensitive modulator, wide-angle deflector, and collinear tunable filter. The first device is based on isotropic (polarization-maintaining) diffraction, while the others – on anisotropic one.

2. Polarization-insensitive modulator

New AO modulator made of KGW single crystal was developed [3], created and tested (Fig. 1). It uses the quasi-longitudinal ultrasonic wave (*QL*) propagating along the axis N_g of dielectric (optical) coordinate system. The modulator can operate two polarization components of light at the same time and can be regarded as a bi-polarization device. Fortunately, the diffraction efficiency values for both polarizations are of the same order (the ratio of AO figure of merit M_2 is 6:10 for KGW), hence, for any polarization of the incident light, the polarization direction remains the same after diffraction and, therefore, the modulator in fact is a polarization-independent device.

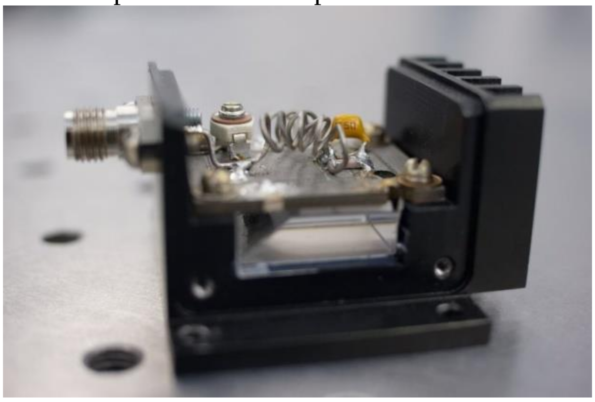

Figure 1. Acousto-optical modulator made on KGW single crystal.

The diffraction coefficient of the created modulator reaches 80% at 532 nm with 1 W of driving power at the frequency about 85 MHz for the transducer width of 2 mm and the length 22 mm . The diffraction coefficient reaches as much as 98% at 633 nm with power 2.5 W. At near infrared range the efficiency is lower: 66% with power 4 W at 1.06 μm. Therefore, the diffraction efficiency of this KGW modulator is only three times lower than the efficiency of traditional AO modulator made of TeO_2. They use ultrasound *L*-mode propagates along [001] direction and light polarization [100] with $M_2 = 34.5 \cdot 10^{-15}$ s^3/kg.

An important feature of the developed modulator is a capability to withstand the high-power laser radiation. AO cell made on KGW crystal maintains its initial temperature in experiment being exposed to 20 kW/cm^2 continuous laser emissions indicating the higher level of radiation resistance than that of paratellurite crystal, which gets warmer (in the same conditions).

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3. Wide-angle deflector

The fact that KGW is biaxial material makes possible to develop a new kinds of AO units on their base, which can not be made with use of uniaxial crystals mostly utilized in acousto-optics. For example, the wide-angle deflector with wide angular aperture and great tuning range can be produced [4]. For this purpose, one must use the geometry with ultrasound wave vector being a tangent to wave surface of two modes so that non-critical phase matching condition is satisfied (Fig. 2). In this case beams with wide angular spectrum ($\Delta\Theta_1$) can be diffracted efficiently while the deflection angle is proportional to acoustic frequency variation ($\Delta\Theta_2 \sim \Delta K \sim \Delta f$). Such AO deflector can operate angular-extended beams, in particular, profiled laser beams, focused radiation, etc. It is useful for imaging applications. And also, the switching time of a high-speed AO modulator is approximately equal to the acoustic transit time through the waist of the focused beam $\tau = d/V_{ac} \sim 1/\Delta\Theta_1$, estimated as 20 ns and less.

In such a way, this deflector combines amplitude and angular effects that make new methods of the laser beam control possible. Unfortunately, this geometry of AO interaction requires quite high driving ultrasonic frequency

$$f = \frac{V_s}{\lambda}\frac{\sqrt{(n_g^2 - n_m^2)(n_m^2 - n_p^2)}}{n_m}$$

up to a few gigahertz for visible range. The minimum velocity of shear ultrasonic waves among discussed crystals is provided by KLuW, which also demonstrates the highest acoustic anisotropy. For this crystal the driving frequencies at wavelengths 1.064 μm and 1.55 μm are 1.1 and 0.8 GHz respectively. These rather high values can be achieved in modern AO units. In the middle infra-red range the frequency is lower.

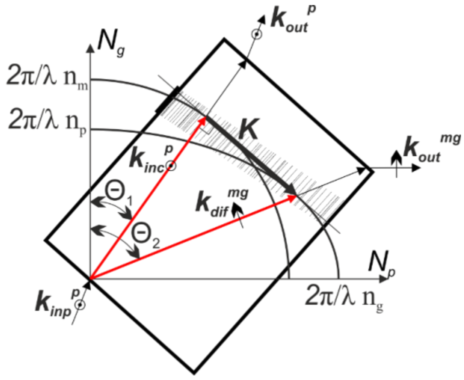

Figure 2. Wave vector diagram for wide-angle deflector.

4. Collinear filter

Collinear AO interaction is always of particular attention as it provides the highest spectral resolution and the minimum driving power. For spectroscopic and imaging applications the wide angular aperture is necessary, that is why one needs to choose directions parallel to the dielectric axes N_m, N_p and N_g. The most suitable acoustic frequencies correspond to N_g axis. The AOTF of this geometry (Fig. 3) is characterized with an acoustic column walk-off like the collinear AOTF on α-SiO_2 [5]. KGW crystal can provide approachable driving frequency 150 MHz with bandwidth for the interaction length of 1 cm can be estimated as δλ = 1.1 nm. Unfortunately, the driving power cannot be calculated, because only a part of photoelastic matrix elements has been measured till now.

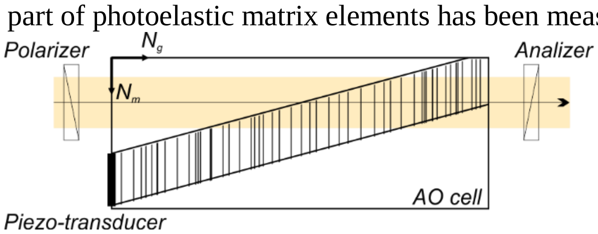

Figure 3. Schematic diagram of collinear filter on KGW single crystal.

5. Conclusion

The new acousto-optic material KGW possess an original complex of features: resistance to high-power laser radiation, optical biaxiality and high AO figure of merit. Therefore, a new family of AO units and devices can be created: modulators, deflectors, filters. They can provide both quantitative and qualitative advantages. New AO modulator for non-polarized high-power light radiation was developed and tested. It demonstrated almost 100% of diffraction coefficient. Extra capabilities may probably be exhibited with implementation of anisotropic diffraction. However, the appropriate elasto-optical coefficients must be experimentally determined.

A very promising AO element developed is the deflector with wide angular aperture and broad range of deflection, which can control high-power Gaussian-profiled laser beams. It is capable to operate with more intensive laser beams than the existing TeO_2 modulators, requiring somewhat higher driving power, but providing an efficient modulation of arbitrary-polarized radiation.

6. References

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Acknowledgments

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