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Design of acousto-optic Q-switch with BAW energy removal

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1. Introduction

The work is devoted to the study of BAW energy removal from acousto-optic (AO) laser Q-switches. For the first time, results regarding acoustic energy removal from AO devices were obtained by V. Molchanov et al. in [1]. This work describes the experimental design of SiO_2-based AO Q-switch with BAW energy removal.

Among the AO devices for controlling laser radiation a special place is occupied by AO Q-switches for solid-state lasers based on fused and crystalline quartz SiO_2. Quartz has a high laser-induced damage threshold but a low AO figure of merit M_2, determinig high RF power consumption of the Q-switch. A typical AO laser Q-switch based on quartz at a wavelength of 1.064 µm consumes RF power on the order of 30 Watts.

A feature of all AO devices is the quadratic dependence of the driving RF power on the laser wavelength. [2] For example, when operating in a pulsed holmium laser Ho^{3+}:YAG at 2.1 µm [3, 4], to achieve the same efficiency as at 1.064 µm, a control RF power on the order of 100 W is theoretically required, which will lead to the destruction of the device. This fundamental feature of AO interaction is a serious limiting factor for use in the mid-IR region. Currently, mid-IR lasers are being intensively developed [3–13]. Quartz-based AO Q-switches are not used, with rare exceptions either in 2 µm range [3, 4] or using KREW crystal family [12, 13].

2. Concept

In any AO device, there are two main principal heat sources: a piezoelectric transducer (PT) and a dissipative absorber of BAW providing the traveling BAW mode. Bulk acoustic absorption in the AO laser Q-switches crystals can be neglected, since they operate at relatively low frequencies of 25–50 MHz.

The dissipative BAW absorber in the AO device is always located on the AO crystal and heats it. The novel concept is based on the conversion of acoustic energy into electrical energy through the use of a second transducer – piezoelectric receiver (PR) in the AO device.

3. Theoretical analysis of BAW reflection from the PR

We consider the acoustic structure shown in Fig. 1 with bonding layers and an *LC* circuit loading to electrical load 50 Ohm.

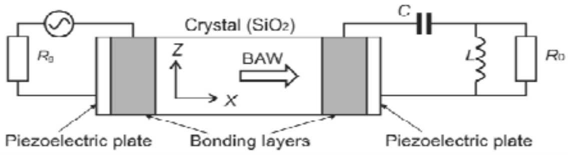

Fig. 1 Schematic representation of an AO architecture with a PT (l.h.s.) and a PR (r.h.s.). The input impedance is *Rg*=50 Ohm; matched electrical load is R_0=50 Ohm.

In this work, the transfer matrix method is used to derive an analytical expression for the reflection coefficient of an acoustic wave incident from the crystal onto the "layered structure + piezoelectric plate" and then to obtain analytical expressions for the parameters of an external matching *LC* circuit connected to the PR, at which the reflection coefficient *R* almost vanishes in a certain frequency band.

Fig. 2 shows four cases of the BAW reflection coefficient |*R*| from the PR vs driving frequency f and the parameters of the matching *LC* circuit. The calculation results reveal the following significant features. Two basic curves are 1 and 2. Curve 1 is calculated taking into account the presence of bonding layers. Curve 2 – when bonding layers are absent. Acoustic refection coefficient *R* is determined by *C* and *L* values and crystals physical constants

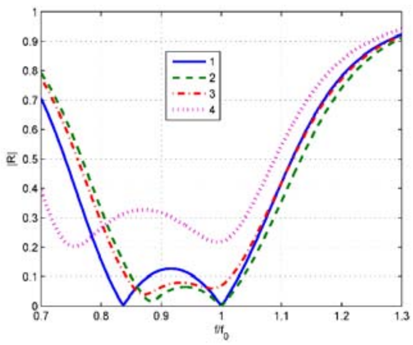

Fig. 2 Reflection coefficient |*R*| vs frequency f/f_0.

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The reflection coefficient can be quite close to zero. $|R|<0.1$, in the acoustic frequency band 0.80–1.03, that is 20% of the central frequency (curve 1).

The reflection coefficient $|R|$ can be tuned after the manufacture of the PR and the matching circuit, regardless of the technology used and the composition of the bonding layers.

4. Experiment

Consider the following acoustic structure: LN PT - SiO_2 crystal - LN PR (Fig. 1). The r.h.s. of this structure is symmetrical to the l.h.s. The PT is supplied with RF power from the generator. In the matching band of 0.80–1.03 (Fig. 2), the acoustic structure transforms the BAW energy into an electrical matched load 50 Ohm with minimum losses.

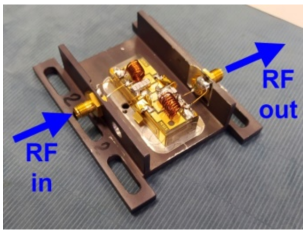

Fig. 3 An experimental SiO_2 AO Q-switch.

Fig. 3 shows the home made SiO_2 AO Q-switch designed according to Fig. 1. The device design corresponds to a typical non-polarized AO Q-switch with light propagating along Z axis, except additional PR for removing the acoustic energy. The central frequency was 24 MHz. The bandwidth was 21–28 MHz, the SWR less than 1.5.

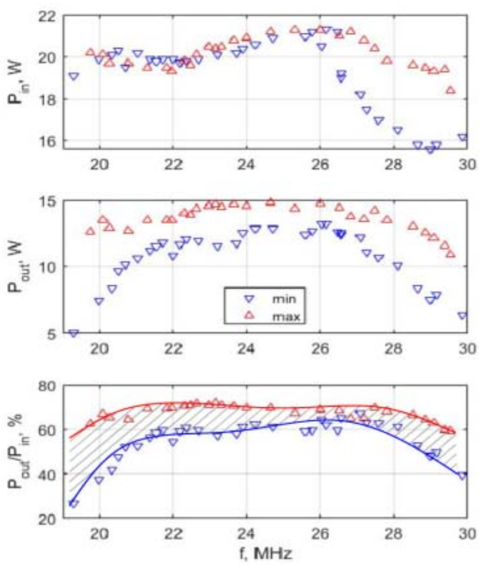

Fig. 4 Phenomenon of acoustic energy removal from an experimental AO Q-switch.

Fig. 4 shows the final experimental results of the present study. The plots show measurement the electrical power P_{in} at the input of the experimental Q-switch, the electrical power P_{out} at the output of the Q-switch, as well as the ratio P_{out}/P_{in} in the frequency range of 20–30 MHz.

In the matching band of 21–28 MHz, the electrical power Pout removed from the device is extremely high and ranges from 60 to 70% of the electrical input power P_{in} 20 W.

5. Conclusion

The experimental study of the home made SiO_2 laser AO Q-switch with LN PT – SiO_2 crystal – LN PR structure fully confirmed the theoretical conclusions and the usefulness of the practical application of the proposed method for removal the BAW energy from the AO Q-switch. The results of this work allow us to foresee a radical solution to the problem of creating high-power consuming AO devices for the mid-IR range3-5 μm.

Acknowledgment

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References

1) V.Ya.Molchanov et al. Proc. **40** Symp. Ultrasonic Electronics, 2019, 3P1-8
2) L.N. Magdich and V.Ya. Molchanov, *Acousto-optic Devices and Their Applications.* (G&B Sci. Publ, NY, 1989) p. 19.
3) N.G. Zakharov et al. Quantum Electron., **40**, 98 (2010).
4) P.A. Ryabochkina et al. Quantum Electron., **47**, 607 (2017).
5) A.A. Voronov et al. Quantum Electron. **36**, 1 (2006).
6) A.V. Podlipensky et al. Opt. Lett. **24**, 960 (1999).
7) V.A. Akimov et al. Quantum Electron. **38**, 205 (2008)
8) V.I. Kozlovskii et al. Opt. Lett. **41**, 1 (2011)
9) J.J. Adams et al. Quantum Electron. **38**, p. 205 (2008).
10) B.G. Bravy et al. Bull. Russ. Acad. Sci. Physics, **80**, 444 (2016).
11) S. Vasilyev et al. Opt. Mater. Express **7**, 2636 (2017)
12) A.V. Pushkin et al. Opt. Lett. **44**, 4837 (2019)
13) A.I. Chizhikov et al. Opt. Lett. **47**, 1085 (2022)