# AN EFFICIENT GENERATOR OF DIFFERENCE FREQUENCIES BASED ON A $TI^{3+}:AL_2O_3$ LASER BICHROMATOR

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*A source of coherent radiation based on a* $Ti^{3+}:Al_2O_3$ *crystal and an* $LiIO_3$ *nonlinear crystal, lasing in the spectral range* 0.34–2.3 μ*m, is considered. A laser bichromator based on a* $Ti^{3+}:Al_2O_3$ *crystal, in which the process of self–synchronization of both channels is realized, has been developed for this purpose. It has been shown that it is possible to broaden the spectral region in the UV and IR spectral ranges.*

The laser based on the $Ti^{3+}:Al_2O_3$ crystal is a highly efficient source of coherent radiation in the spectral range 650 – 1180 nm (Refs. 1–3). One of the most important improvements of the sources based on $Ti^{3+}:Al_2O_3$ lasers have taken is broadening of the range of lasing wavelengths by employing nonlinear converters. Already in the first studies of the lasing properties of the $Ti^{3+}:Al_2O_3$ lasers, the possibility of broadening due to lasing of harmonics has been demonstrated.[4,5]

The present paper is devoted to a description of a source of coherent radiation which operates in the spectral range 0.34 – 2.3 mm and is based on a $Ti^{3+}:Al_2O_3$ laser which can be tuned over the range 680–1050 nm.

The main difficulty in solving this problem is obtaining tunable radiation in the spectral regions 525–680 and 1050–2300 nm. It is possible to obtain coherent radiation in these spectral intervals by means of summation or subtraction of the radiation of a $Ti^{3+}:Al_2O_3$ laser and the radiation of a pumping laser (a $Nd^{3+}$:YAG laser). But there is a serious problem here which consists of temporal detuning of the pulses which are mixed as aresult of a delay between the lasing pulse of the $Ti^{3+}:Al_2O_3$ laser and the lasing pulse of the pump laser, the amplitude of which depends on the lasing wavelength, the pumping level, and other factors.[1] The last circumstance, as was confirmed in Refs. 6 and 7, seriously impedes the realization of this process and decreases its efficiency to an unacceptably low level.

The method of lasing at difference frequencies, which eliminates the effect of this delay in a natural way, was proposed in Ref. 1. It is based on the use of a $Ti^{3+}:Al_2O_3$ laser operating in the bichromatic mode with the wavelengths that correspond to the levels of identical amplification. The bichromator emits two spectral components, namely the shortwave $\lambda_{sh}$ and the longwave $\lambda_l$, which are synchronously tuned from the ends of the range toward its center so that the amplification coefficients (the cross section of the lasing transition) are identical. In this case, the lasing pulses of the $Ti^{3+}:Al_2O_3$ laser, which emits radiation simultaneously at $\lambda_{sh}$ and $\lambda_l$, will have the same width, shape, and delay relative to the pumping pulse. These considerations are also valid when we transfer to the harmonics of the $Ti^{3+}:Al_2O_3$ laser bichromator ($2\omega_{sh}$ and $2\omega_l$) and, consequently, the problem of covering the spectral ranges 525–680 and 1050–2300 nm can be solved with the help of the generators of the difference frequencies, namely $2\omega_{sh} - \omega_l$ and $2\omega_l - \omega_{sh}$.

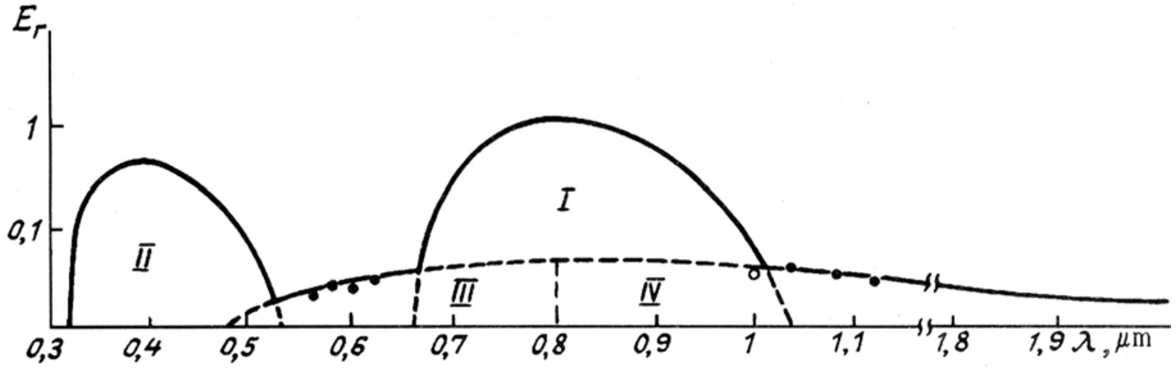


*FIG. 1. The pulse energy as a function of the radiation wavelength: lasing of laser a* $Ti^{3+}:Al_2O_3$ *laser (I); lasing of the second harmonic in a* $LiIO_3$ *crystal (II); lasing of the difference frequency* $2\omega_{sh} - \omega_l$ *in a* $LiIO_3$ *crystal (III); lasing of the difference frequency* $2\omega_l - \omega_{sh}$ *in a* $LiIO_3$ *crystal (IV). The experimental results are indicated by dots for the ranges III and IV.*

The source of coherent radiation which can be tuned over the range 0.34–2.3 μm based on the $Ti^{3+}:Al_2O_3$ laser bichromator consists of three basic units: the laser bichromator lasing at the fundamental harmonic in the range 680–1050 nm, the generator of the second harmonic (340–525 nm), and the generator of the difference frequencies

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$2\omega_{sh} - \omega_l$ or $2\omega_l - \omega_{sh}$, which covers the ranges 503–800 and 800–2300 nm, respectively (Fig. 1). An optical diagram of the source is shown in Fig. 2.

The laser bichromator has a common arm, in which the $Ti^{3+}:Al_2O_3$ active element with dimensions 6×6×18 mm and activator concentration C = 0.12 wt.% is enclosed. The radiation of the second harmonic of the $Nd^{3+}$:YAG laser with energy $E$ = 120 mJ per pulse and pulse duration $\tau$ = 15 ns was used for bilateral pumping of the active element. The spectral splitter (SS) splits the radiation between the two output channels in which the selectors and the output mirrors are placed. The SS has a reflectance of ~ 98% for $\lambda > 800$ nm and a transmittance of 95% for $\lambda < 800$ nm. The wavelength region of free dispersion of the selectors is more than 400 nm while the bandwidth is about 1 nm. The selectors are synchronously or independently tuned over the operating spectral range of the $Ti^{3+}:Al_2O_3$ laser.

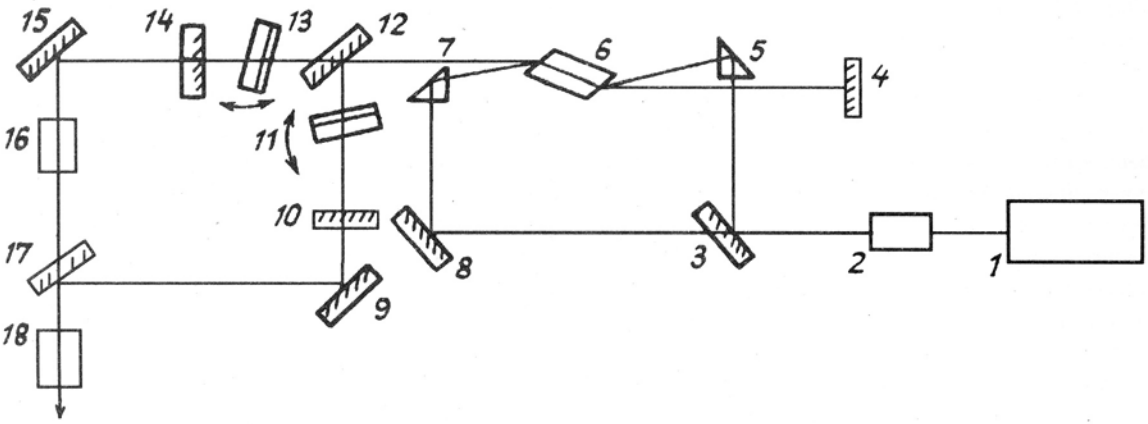


*FIG. 2. Optical diagram of a coherent radiation source based on a $Ti^{3+}:Al_2O_3$ crystal. 1) $Nd^{3+}$:YAG laser ; 2) KTP crystal; 3) beam splitter; 4) "nontransmitting" mirror; 5, 7) rotating prisms; 6) $Ti^{3+}:Al_2O_3$ crystal, 8, 9, and 15) reflecting mirrors; 10, 14) output mirrors of the cavity; 11, 13) selectors; 12, 17) spectral splitters; 16, 18) $LiIO_3$ crystals.*

After the SS is removed, the laser operates with one channel and can be tuned over the range 680 – 1050 nm with ~ 0.15 nm half–width of the lasing line and ~ 35 mJ peak energy per pulse. This radiation arrives at the output of the device or at the $LiIO_3$ crystal of the second harmonic generator. In the second case, the radiation is emitted in the wavelength range 340–525 nm.

When the SS is inserted into the beam, the $Ti^{3+}:Al_2O_3$ laser operates as a bichromator. In order to obtain tunable radiation emission in the wavelength ranges 503–680 and 1050–2300 nm, the laser bichromator must emit temporally synchronized pulses with energies which differ by a factor of 5–10 to provide optimal conditions for lasing at the frequency $2\omega_i - \omega_j$. The energy of frequency–doubled lasing was chosen two or three times higher than the pulse energy in the second channel of the laser bichromator. In this case, lasing at the difference frequency $2\omega_i - \omega_j$ is achieved with maximum efficiency. The experimental results are shown in Fig. 1. It can be seen that, when using the $LiIO_3$ crystals (provided by L.I. Isaenko, Novosibirsk) with dimensions 10×10×20 mm, whose ends are at an angle of 42°, pulse energies reaching 1 mJ are obtained using the doubler and generator in the wavelength ranges 503–680 and 1050–2300 nm. The maximum efficiency of conversion was determined in our case by the optical strength of the nonlinear crystals.

The angle of synchronism of a $LiIO_3$ crystal lasing at the difference frequency (collinear interaction) is close to the angle of synchronism for lasing at the second harmonic. The maximum deviation is ~ 3° at the ends of the spectral range and decreases in the direction of the maximum of the tuning curve. For example, at $\lambda$ = 698 nm, the angle of synchronism for lasing at the second harmonic is ~ 51°, while for the difference frequency it is ~ 49° at $\lambda_l$ = 920 nm.

In conclusion, we note that it is possible to broaden the operational wavelength range in the UV and IR ranges of the spectrum by lasing at the third and fourth harmonics of the $Ti^{3+}:Al_2O_3$ laser at and the difference frequency $\omega_{sh} - \omega_l$ of the laser bichromator. Further increase of the efficiency of the nonlinear conversions is possible with the use of the new more effective BBO and LBO crystals.

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