# Laser passive Q-switches based on the dye-doped polyurethane for high-energy neodymium lasers


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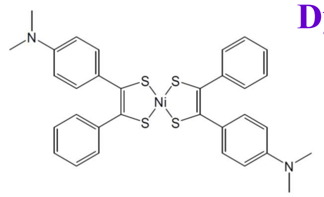
## Introduction

Industrial need for lasers emitting high energy and power light is constantly growing. To obtain high-power single-pulses, a change (increase) in the optical cavity quality factor, the so-called Q-switching, is used. Passively Q-switched lasers are the most reliable because the passive Q-switch is based on a mechanism that changes the laser cavity losses in response to changes in the laser internal photon density. Solid-state Q-switches with the dye-doped polymers are not sensitive to the polarization quality of the radiation, are isotropic in both the initial and bleached states, and do not require polarizers or other anisotropic cavity elements for their operation (active Q-switching).

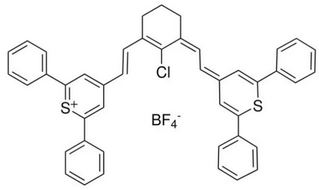
## The aim of the study

This work concerns the investigations of optical and nonlinear optical properties for the Q-switches based on organic dyes included in a polyurethane matrix. Possibility of obtaining powerful single-pulse nanosecond generation in a neodymium laser has been tested, and the pulse energy and time characteristics have been studied.

## Dyes



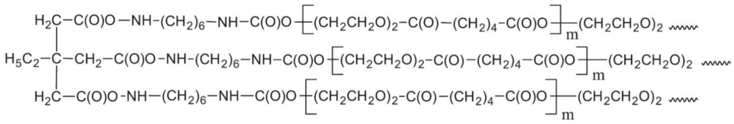

the organo-nickel complex **BDN** (bis-(4-dimethylaminodithiobenzil)-nickel)



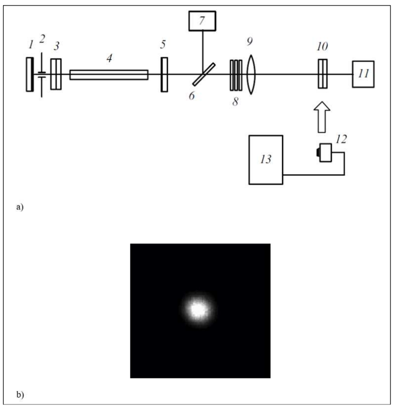

**IR-1061** (4-[2-[2-chloro-3-[(2,6-diphenyl-4H-thiopyran-4-ylidene)ethylydene]-1-cyclohexen-1-yl]ethenyl]-2,6-diphenylthiopyriliumtetrafluoroborate)

## Polyurethane matrix was obtained from :

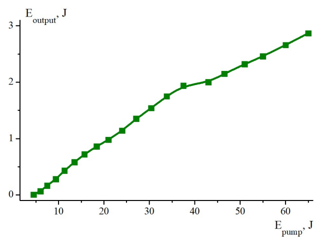
1.6-diisocyanatohexane $C_8H_{12}N_2O_2$, poly[di(ethylene glycol) adipate] $HO(-CH_2CH_2O)_2-[C(O)-(CH_2)_4-C(O)O-(CH_2CH_2O)_2]_m-H$, trimethylolpropane $C_6H_{14}O_3$.



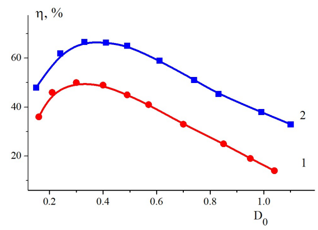

## Results and discussion




Experimental scheme for the studying nonlinear transmission (a) and the laser beam cross section at the sample location (b): 1 – a "deaf" mirror; 2 – a diaphragm; 3 – the Q-switch; 4 – the $Nd^{3+}$:YAG rod; 5 – an output mirror; 6 – a beam splitter; 7, 11 – photodiodes; 8 – neutral density filters; 9 – lens; 10 – the sample under study; 12 – a CCD camera; 13 – an oscilloscope.




Output energy of the laser as a function of pumping input energy in a free-running mode.



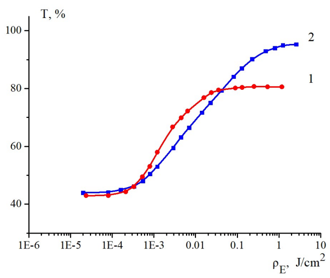

Free generation conversion efficiency into a single pulse on the initial optical density of the polymer Q-switch for the BDN (1) and IR-1061 (2) dyes.

The obtained data on η indicate a more effective clearing of the Q-switch on the IR-1061 dye in comparison with the BDN one. The ground state absorption cross section at $\lambda$=0.1064 μm of the IR-1061 dye is significantly higher (22 times) than for the BDN. The consequence is a greater value of the modulation depth for the IR-1061 dye ($\Delta T$=51.3%), compared to the BDN ($\Delta T$=37.6%) at the equal $T_0$.

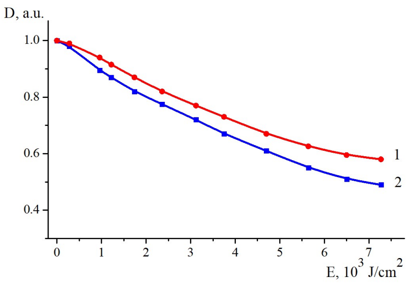
The saturation intensity $I_s$ for the BDN is significantly less than that of the IR-1061 dye due to the large difference in the excited state relaxation time $\tau_s$, 1.5 ns and 50 ps, correspondingly. For this reason, to obtain the same single-pulse energy, one needs to use a Q-switch on the IR-1061 dye with a larger $T_0$ value.

Photostability of the IR-1061 based sample is somewhat lower than that of the BDN one. Oxygen, in particular singlet oxygen of a high reactivity, is known for its ability to oxidize polymethine dyes more efficiently than organometallic complexes.

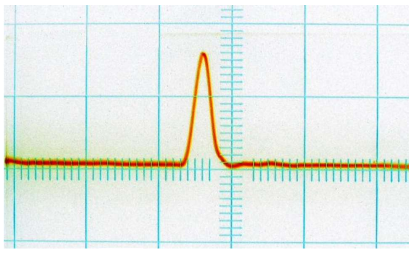
With the BPL 66/33 power supply of the pump energy 65 J, a single pulse of 0.96 J was obtained on the IR-1061 dye Q-switch at $T_0$ = 10%. Duration of the single pulse at half maximum was 11 ns. In a case of $T_0$ = 8%, a single pulse with a duration of 16 ns and an energy of 0.78 J was obtained.




Nonlinear transmission on the energy density of radiation incident on the Q-switch: for the BDN (1) and IR-1061 (2) dyes.




Dye optical density change at the absorption maximum in the polymer matrix on the energy dose of irradiation with a mercury lamp: for the BDN (1) and IR-1061 (2) dyes.



Oscillogram of a laser single pulse with the Q-switch on the IR-1061 dye ($T_0$ =10%). Time scale is 50 ns/div.

## Conclusions

The studies in this work showed that the passive Q-switches based on the highly resistant aliphatic polyurethane matrix, activated with the thiopyrylo-4-tricarbocyanine dye provided powerful single pulses of an energy ~1 J. Efficient Q-switching with a polymethine dye is a result of more optimal linear and nonlinear spectral properties in comparison with the widely used nickel-organic complex. The laser performance of a neodymium laser on a $Nd^{3+}$:YAG active element placed in a highly reflective samarium diffuse reflector was tested. The pumping efficiency as a function of the capacitor discharge time was investigated. It was shown that to obtain maximum generation energy, the pumping duration from a flash lamp should be close to the upper level lifetime of the laser transition in the active element. In the free mode, 5.1% efficiency was obtained, which was close in efficiency to the $Nd^{3+}$:$KGd(WO_4)_2$ lasers. Thus, the highly efficient generation of the powerful single pulses obtained in this work, exceeds the best analogues of Q-switched lasers due to a highly beam resistant original polymer matrix in the aliphatic polyurethane based Q-switches. The use of the polymethine dye in the Q-switches provided significantly increased efficiency of a pulsed neodymium laser with passive Q-switching.