SARATOV FALL MEETING SFM '22

SARATOV FALL MEETING XXVI

Threshold effect under High-Power Laser Limiting for Flat-Top Pulse Shape

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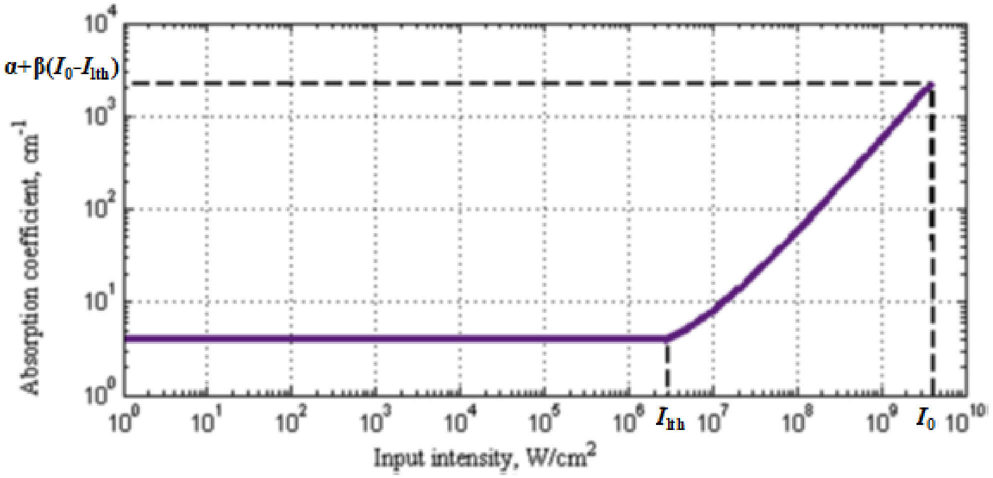
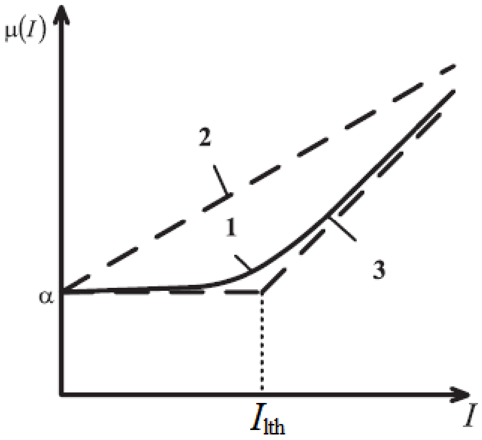
ИНМЭ РАН

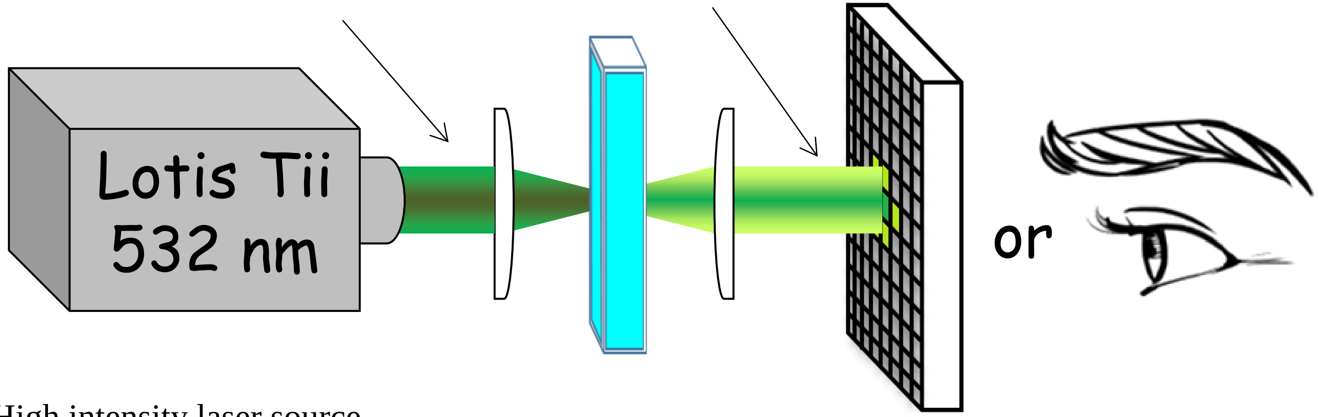
The principle of limiting laser radiation



Threshold dependence of the absorption coefficient on intensity



True dependence of absorption coefficient on intensity (1), non-threshold model (2) and threshold model (3)



Incident high-intensity radiation

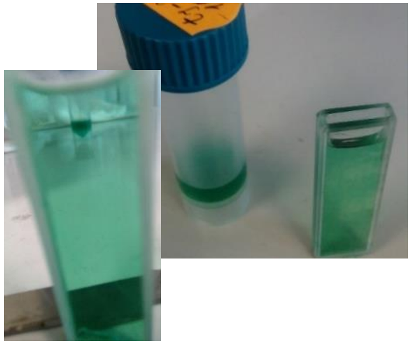
Outgoing low-intensity radiation

Eyes or optical radiation sensor

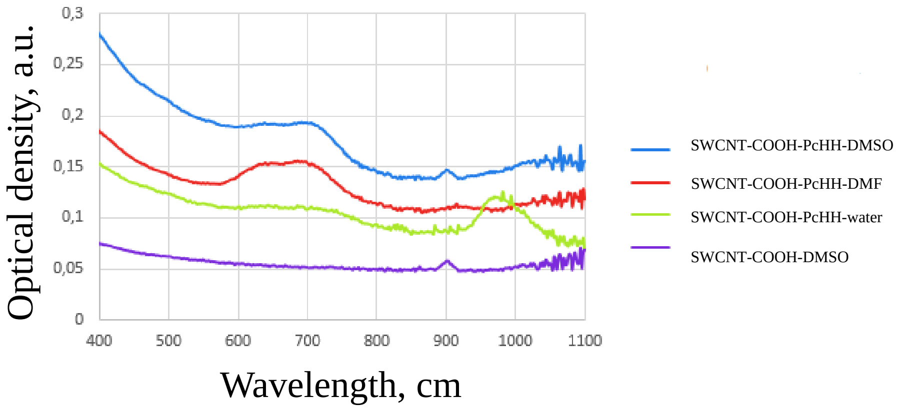
High intensity laser source

Nonlinear optical material

Phthalocyanines as an absorbing material for laser technology

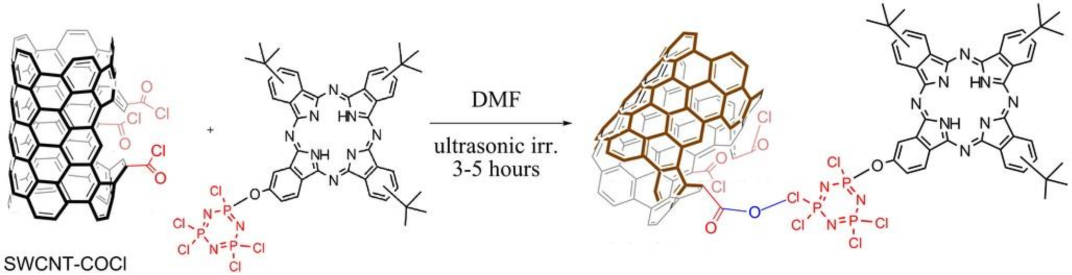


Solutions of asymmetrically substituted phthalocyanine complex containing one pentachlorocyclotriphosphazene fragment at the periphery (PcHH)



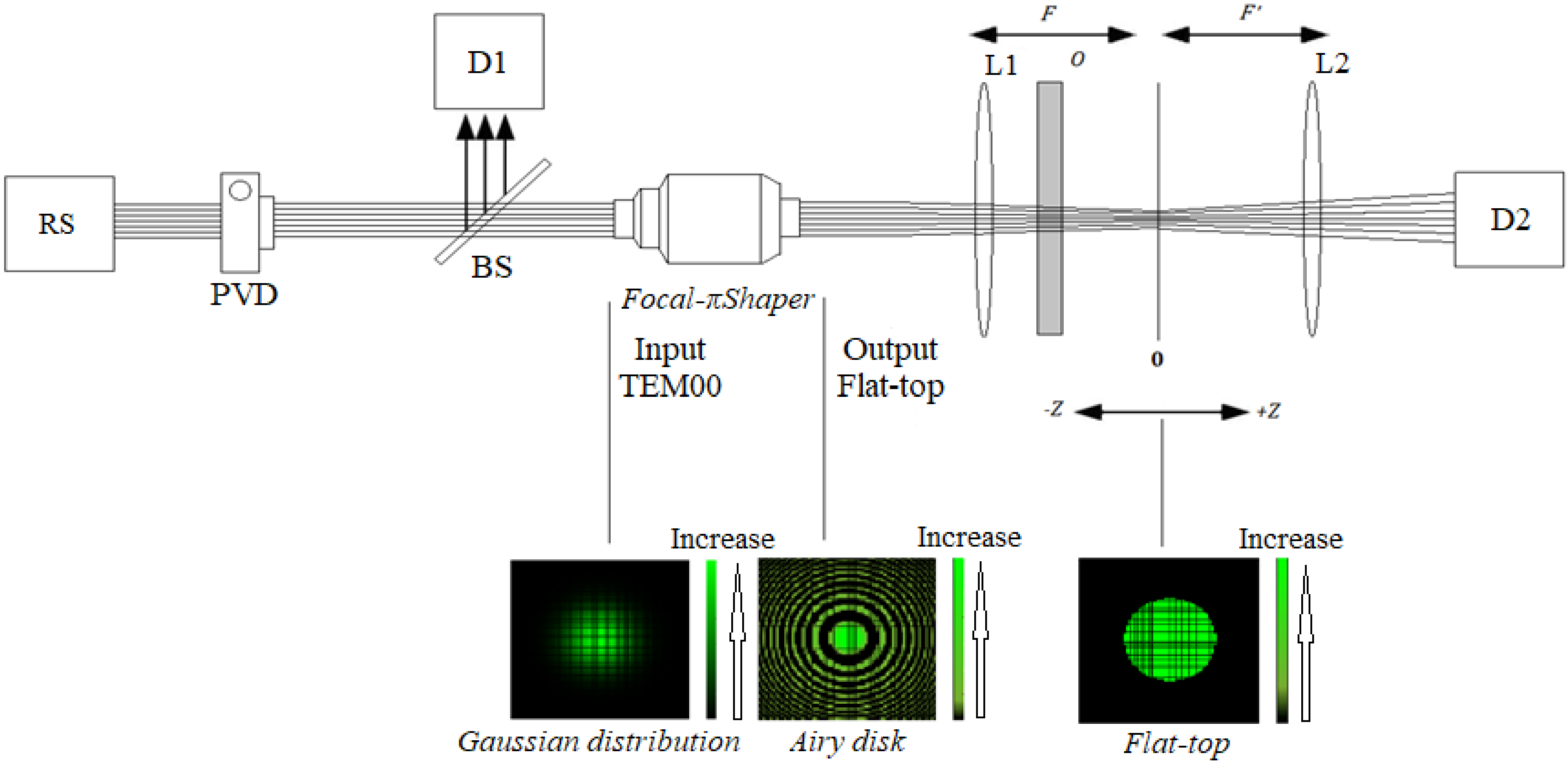
Optical density of the studied samples

Conjugates of single-walled carbon nanotubes (SWCNT)



Conjugates of single-walled carbon nanotubes with low-symmetric phthalocyanine complex containing penta-the chlorocyclotriphosphazene part

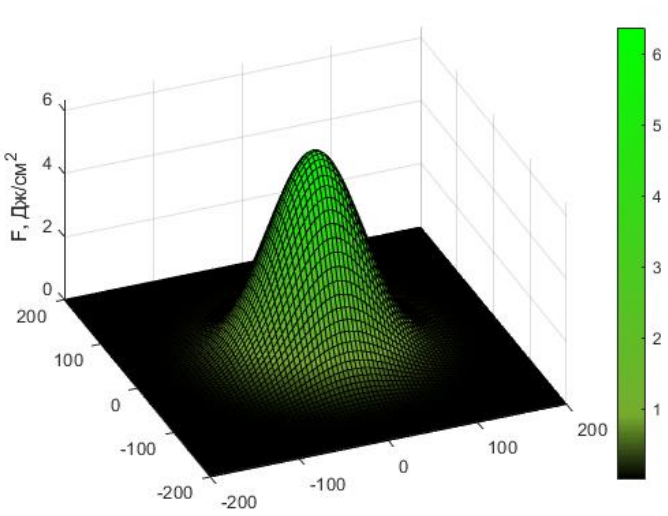
Laser systems with Focal π-Shaper



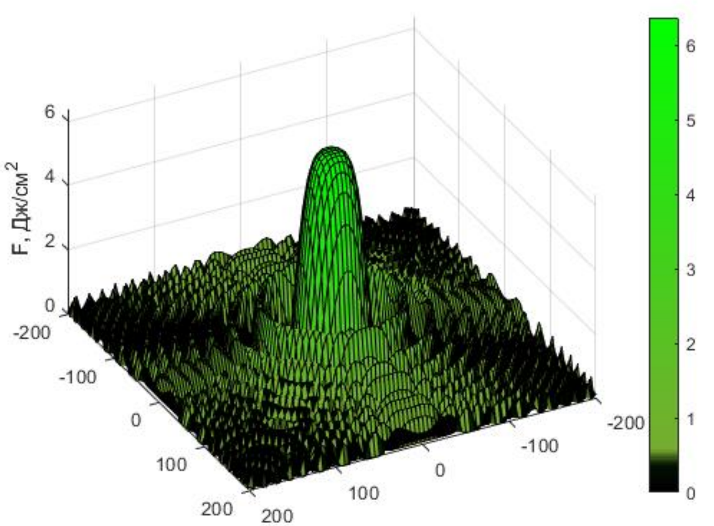
RS – radiation source; PVD – power varying device; BS – beam splitter;
D1, D2 – detectors; L1, L2 – lens

The job of the writer is as follows. Gaussian distribution of collimated beam intensity. The TEM00 of the laser is transformed in to a flat distribution at the top (similar to the Greek letter π). The output beam is also collimated and has approximately the same dimensions as the input beam

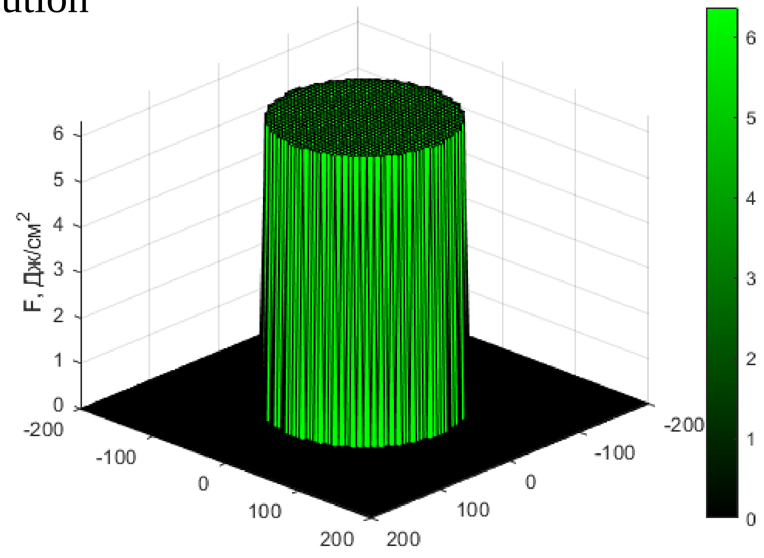
Profiles of laser radiation that are used in an optical system with Focal π-Shaper



Gaussian distribution



Airy Disk



Flat-top

Description of nonlinear interaction in the case of intensity distribution in a rectangular pulse

The dependence of the absorption coefficient on the incident intensity $\mu(I)$ is given by the following expression:

$$\mu(I) = \alpha + \beta(I - I_{\text{th}})\eta(I - I_{\text{th}}), \tag{1}$$

where I_{th} is the threshold intensity, η is the Heaviside function, which has only two values 0 and 1, α is the linear absorption coefficient, β is the nonlinear absorption coefficient.

The total energy of the pulse U can be expressed as follows:

$$U(\rho, \varphi, t) = \int_{-\infty}^{+\infty} \left(\int_{0}^{2\pi} \int_{0}^{\infty} I(\rho, \varphi, t)\rho d\rho d\varphi \right) dt. \tag{2}$$

Normalized transmission for the case of the threshold model (1) for the total pulse energy (2) in measurements by the method of fixed material location is described by the following expression:

$$T_{\text{норм}} = exp\left(-\beta \frac{2}{\pi^{3/2}\tau_{1/e} w_{1/e^2}^2} \left(U_0 \frac{1}{w_{norm}^2} - U_{\text{пор}} \right) d \right), \tag{3}$$

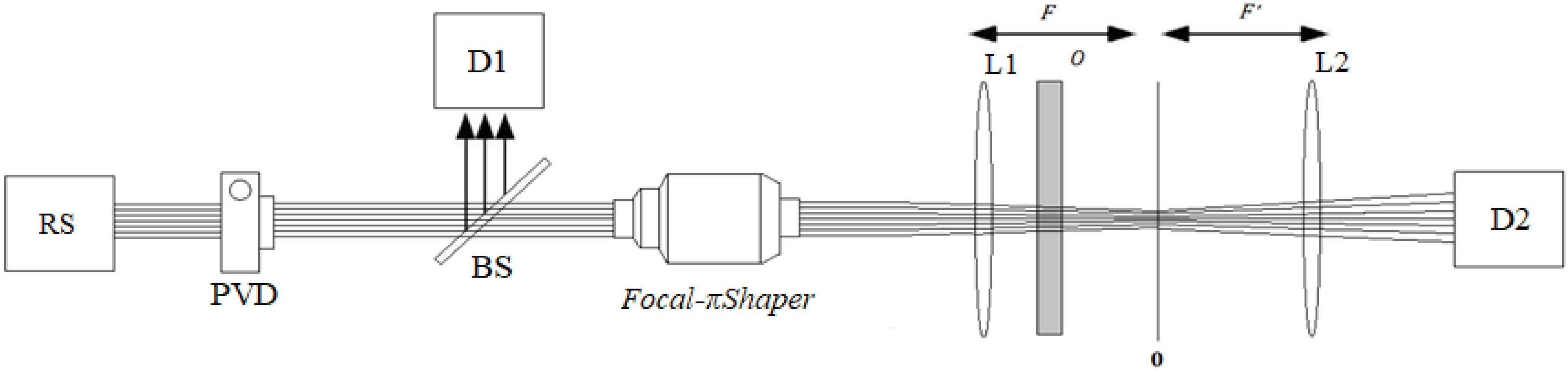
where τ and w are the characteristics of a laser beam with a rectangular cross–section profile, namely its duration and radius, respectively.

In (3) the value of the normalized transmission: $w_{\text{norm}} = \sqrt{1 + \frac{z^2}{z_0^2}}$.

1. Терещенко С. А., Подгаецкий В. М., Герасименко А. Ю., Савельев М. С. Пороговый эффект при нелинейном ограничении интенсивности мощного оптического излучения // Квантовая электроника. – 2015. – Т. 45, – № 4. – С. 315-320.

2. Tereshchenko S. A., Savelyev M. S., Podgaetsky V. M., Gerasimenko A. Yu., Selishchev S. V. Nonlinear threshold effect in the Z-scan method of characterizing limiters for highintensity laser light // Journal of Applied Physics. – 2016. – T. 120. – C. 093109-1-093109-8.

Scheme for studying the nonlinear optical response of a material using Focal π-Shaper



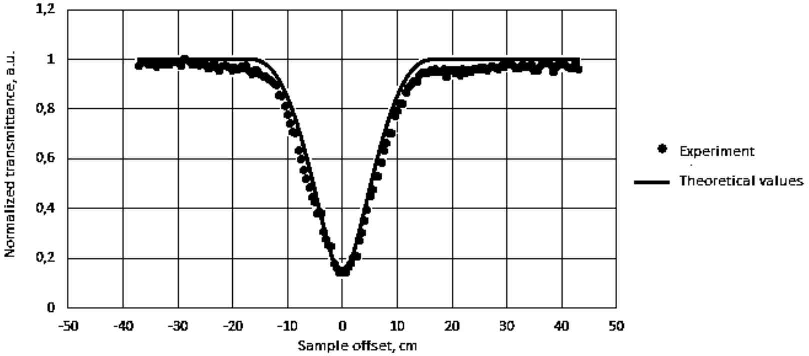
RS – radiation source; PVD – power varying device; BS – beam splitter;
D1, D2 – detectors; L1, L2 – lens

Experimental setup

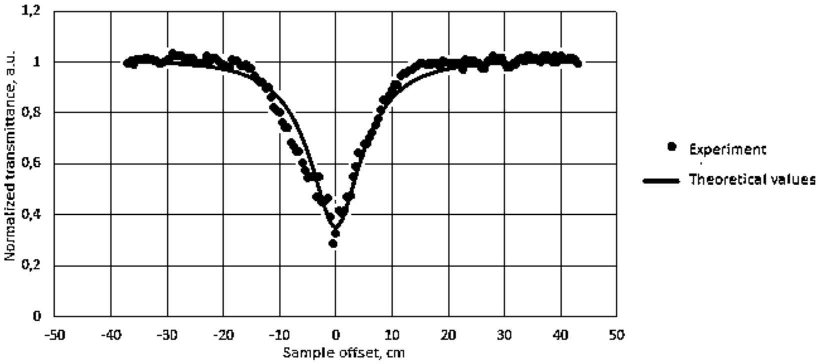
Calculation of the nonlinear absorption coefficient by Z-scan with an open aperture

Working substance of the limiter	Total pulse energy, µJ	Input fluence, J/cm^2	Threshold input fluence, J/cm^2	Linear absorption coefficient, cm^{-1}	Nonlinear absorption coefficient, cm·GW^{-1}
SWCNT-COOH+PcHH in H_2O	330	3,04	0,15	1,59	82,22
SWCNT-COOH in DMFA	375	3,97	0,08	1,00	60,86
SWCNT-COOH+PcHH in DMFA	330	2,44	0,10	1,54	125,25
SWCNT-COOH in DMSO	330	2,80	0,08	0,66	44,71
SWCNT-COOH+PcHH in DMSO	330	2,55	0,13	1,76	127,43

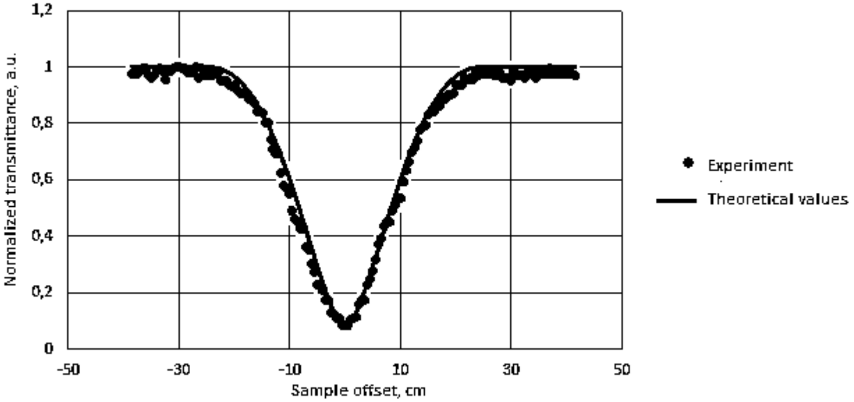
Dependence of the normalized transmission on the sample displacement



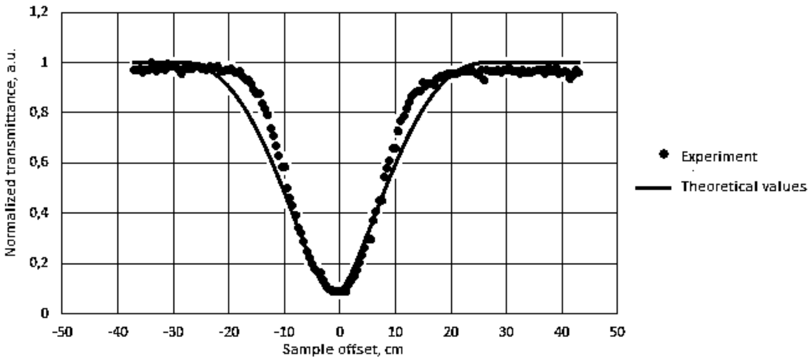
SWCNT-COOH+PcHH in H_2O



SWCNT-COOH in DMSO

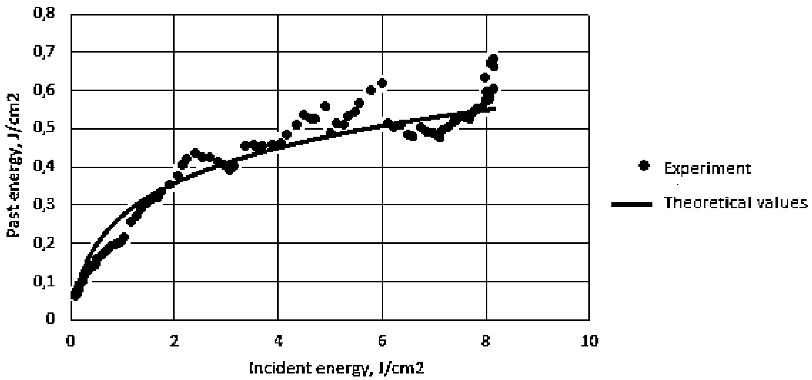


N7 SWCNT-COOH+PcHH in DMFA

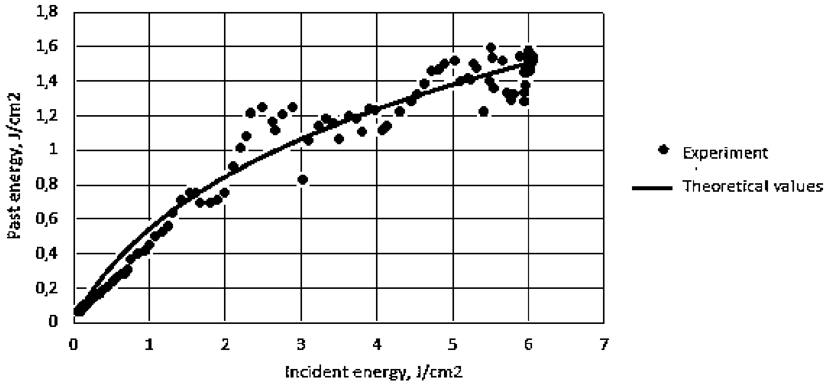


N11 SWCNT-COOH+PcHH in DMSO

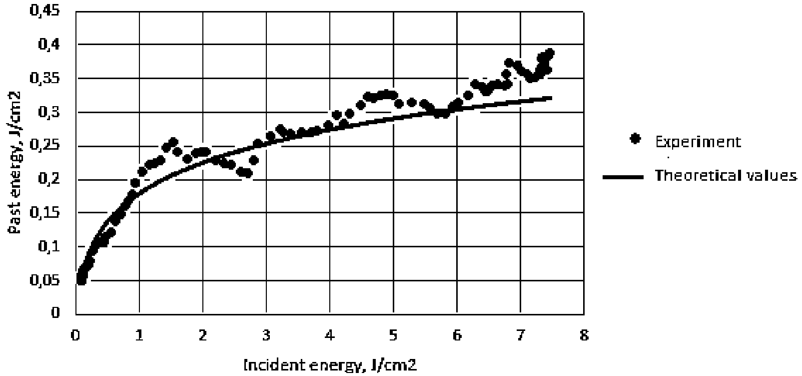
Dependence of the past energy on the falling energy



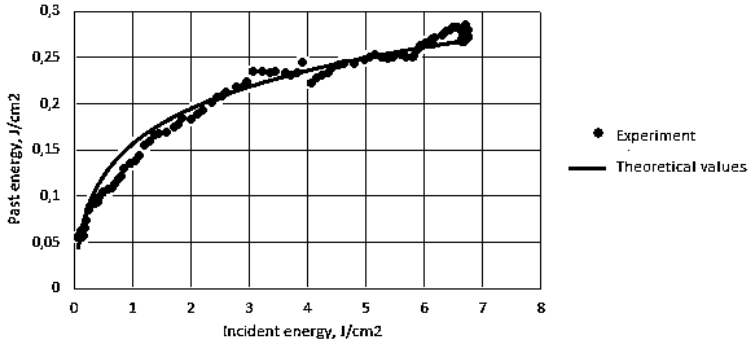
N3 SWCNT-COOH+PcHH in H_2O



SWCNT-COOH in DMSO



SWCNT-COOH+PcHH in DMFA



SWCNT-COOH+PcHH in DMSO

Conclusion

1. An analytical solution is obtained for the nonlinear radiation transport equation for the threshold dependence of the absorption coefficient on the intensity of a laser beam that has a flat-top intensity shape.

2. The use of a threshold model makes it possible to describe more accurately the experimentally obtained Z-scan curve with an open aperture..

3. A laser radiation limiter of this design is a passive protection device, the turn-on speed of which, in accordance with the results obtained, is about 16 ns, which is faster than any active laser radiation protection device.

4.In all cases, the nonlinear absorption is greater in the case of conjugates of phthalocyanines with carbon nanotubes compared to the initial carboxylated ones. SWCNT-COOH+PcHH in DMFA and SWCNT-COOH+PcHH in DMSO has nonlinear absorption 125 and 127 $cm \cdot GW^{-1}$ and SWCNT-COOH in DMFA and SWCNT-COOH in DMSO 60 and 44 $cm \cdot GW^{-1}$.

5. The developed dispersions are promising for the creation of nonlinear optical materials with a high attenuation coefficient, low threshold intensity, and a high damage threshold.

Thank you for reading the material!