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UDC 621.373.826

EFFICIENT IN-BAND PUMPED $Er{:}KY(WO_4)_2$ LASER

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Applications of erbium lasers emitting in the eye-safe spectral range around 1.6 µm include laser range finding, ophthalmology, fiber-optic communication systems, and optical location. Continuous-wave (CW) room-temperature laser operation was demonstrated for several Er,Yb-codoped crystals: garnets, vanadates, oxoborates, and tungstates. However, the intrinsic slope efficiency is limited to be about 60 % due to the large quantum defect. $Er,Yb{:}KY(WO_4)_2$ lasers emitting in the spectral range around 1.6 µm have already been realized by pumping near 1 µm. Using CW Ti:sapphire laser at 930 nm as a pump source a slope efficiency of 1 % and an output power of 2.8 mW were obtained at the wavelength of 1540 nm [1]. The diode-pumped at 980 nm laser operation was obtained with maximum output power of 54 mW and slope efficiency up to 1.6 % [2].

In-band pumping in the spectral range 1.5-1.6 µm ($^4I_{15/2}$-$^4I_{13/2}$ transition) of Er^{3+} reduces the quantum defect and thermal load of the crystal and enables to increase strongly laser efficiency and output power in comparison with pumping of Er,Yb-codoped crystals near 1 µm. However, due to significant upconversion losses the maximal erbium concentrations are limited. Thus, owing to poor absorption near 1.5 µm of erbium comparatively long crystals with several centimeters in length have to be used. This fact imposes restrictions on the quality of pump beam.

In this work we present the spectroscopy and, for the first time to our knowledge, efficient continuous wave operation of $Er{:}KY(WO_4)_2$ crystal under in-band pumping by a compact diode-pumped $Er,Yb{:}GdAl_3(BO_3)_4$ laser.

Absorption spectra of Er^{3+} in KYW at room-temperature recorded with a spectrophotometer Cary-5000 in the spectral range 1440-1640 nm (transition $^4I_{15/2}\rightarrow{}^4I_{13/2}$ of erbium ions) are presented in Fig. 1 and show essential differences of absorption properties for polarizations of light along the three principal crystallooptic axes N_g, N_m, and N_p. The absorption cross-section is higher for light polarization $E//N_m$ with the maximum of 2.4×10^{-20} cm^2 at 1534 nm. This wavelength corresponds to emission wavelengths of InGaAsP/InP laser diode sources, that gives opportunity to consider Er:KYW crystal to be prospective laser material for laser diode in-band pumping.

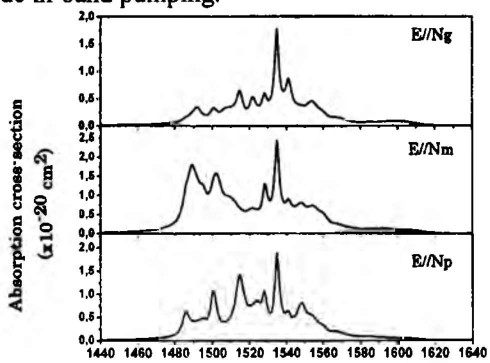

Fig. 1. Room-temperature polarized absorption cross-section spectra of Er:KYW crystal in the spectral range 1440-1640 nm

The stimulated emission cross-section spectra calculated by the reciprocity method using the energy position of the Stark levels of $^4I_{13/2}$ and $^4I_{15/2}$ manifolds are shown in Fig. 2. There is a broad emission features in the spectral range 1570-1630 nm that evidences of opportunity to realize mode-locked femtosecond in-band pumped Er:KYW laser.

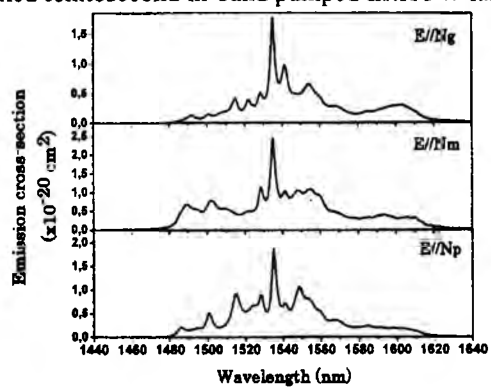

Fig. 2. Polarized emission cross-section spectra of Er:KYW crystal in the spectral 1440-1640 nm

For lifetime measurements optical parametric oscillator emitted at about 1530 nm on the basis of β-$Ba_2B_2O_4$ crystal pumped by the third harmonic of Nd:YAG laser (355 nm) with pulse duration of 20 ns was used as an excitation source. The luminescence of a sample was collected from its face irradiated by the excitation beam, passed through the 0.3-m monochromator, and registered by an InGaAs photodiode coupled with a 500 MHz digital oscilloscope.

It is well-known that radiation trapping strongly influences the measured lifetime of Er^{3+} ions in crystals and glasses because of significant overlap of the absorption and emission bands. Comparatively high refractive index of Er:KYW also increases the probability of reabsorption even in optically thin samples because of the total internal reflection. In our experiments we used a fine powder of Er(0.5 at.%):KYW crystal immersed in glycerin. For the powder sample in glycerin the lifetime decreased with the decreasing of powder concentration in suspension. Starting from a certain powder content, the lifetime remained constant despite for further dilution, that indicates negligible reabsorption influence. The lifetime of $^4I_{13/2}$ level was measured to be 3.1 ms (Fig. 3).

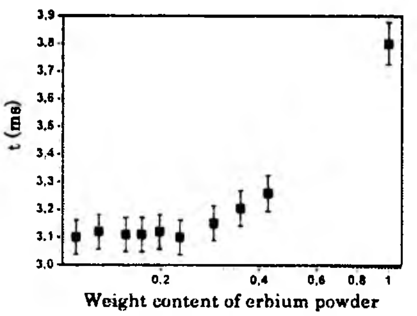

Fig. 3. Lifetime if the Er(0.5 at. %):KYW crystalline powder immerced in glycerin

The laser experiments were performed with a 3-mirror cavity. The plane-plane N_p-cut Er(2 at. %):KYW crystal with a length of 14.5 mm antireflection coated for both pump and lasing wavelengths was mounted on the copper heatsink without active cooling. As a pump source a diode-pumped Er,Yb:GdAB laser with output power of 650 mW at 1531 nm was used. The intensity profile of the laser output was close to Gaussian TEM_{00}-mode with bean propagation factor M^2<1.2. The combination of two lenses (f_1=25 mm, f_2=60 mm) was used to focus polarized ($E//N_m$) pump beam into the gain medium, and pump beam spot radius was measured to be 35 μm ($1/e^2$ intensity). The cavity setup for laser experiments is presented in Fig. 4.

Figure 5 shows input-output characteristics of CW in-band pumped Er:KYW laser. The absorbed pump power was calculated from the measured absorption coefficient at the laser threshold. For output coupler transmittance of 1 % the CW $E//N_m$ linearly polarized output power of 23 mW with slope efficiency near 16 % was obtained at 1609.5 nm at 340 mW of absorbed pump power. The laser threshold was about 190 mW of absorbed pump power. With 2.2 % output coupler transmittance slope efficiency increased up to 27 % resulting in maximum output power of 35 mW. For 2.7 % output coupler transmittance a maximum output power of 31 mW with slope efficiency of 25 % was obtained.

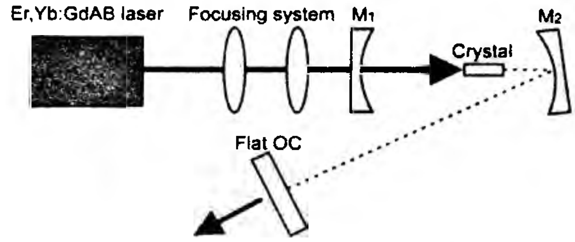

Fig. 4. Cavity setup for laser experimets

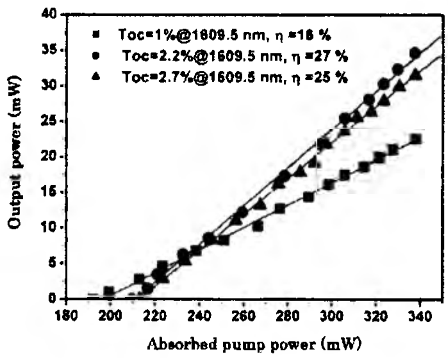

Fig. 5. Input-output characteristics of CW in-band pumped Er:KYW laser

The spatial profile of the output beam was TEM_{00} mode with M^2 <1.2 (inset in Fig. 6). During laser experiments the laser wavelength was measured to be 1609.5 nm and did not depend on the output coupling (Fig. 6).

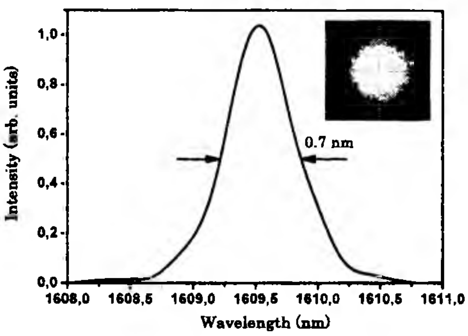

Fig. 6. Laser spectrum of in-band pumped Er:KYW laser. The inset: intensity profile of the laser output

In conclusion, a CW in-band pumped room-temperature Er:$KY(WO_4)_2$ laser was realized for the first time to our knowledge. Maximum slope efficiency of 27 % and output power of 35 mW at 1609.5 nm were achieved with beam propagation factor M^2<1.2.

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UDC 681

MONITORING OF DISTRIBUTION OIL TRANSFORMERS USING THE SENSOR TECHNIQUE

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Introduction

Power transformers are key equipment for transfer and distribution of the electric power. Considering the significance of the power transformers in the electric system, their price and possible damages occurred by accidents, it is necessary to pay attention to their higher prevention.

Power transformers must be designed so, that the effect of short-circuits currents, which can emerge in the place, will not start up on them the destruction or the deformation of the electric, mechanical or thermal character. Except for permanently deformation results of the effects of short-circuit current come to also by correct dimensioning of electric equipment to progressive ageing, which can make worse his mechanical properties.

Experimental measurement

As an example of analysis and monitoring of thermal processes in transformer by using the thermovision and method of monitoring refrigerating curves we will introduce experimental measurement with distributional oil transformer with natural cooling system 22/0.4 kV, 30 kVA, which is located in the Laboratory of electrical machine diagnostics of the University of Zilina. [2]

To measure the windings temperature we used two optical detectors with measuring unit Neoptix, which were installed on the top and the middle part of the middle primary phases (Fig.1 – white stripes).

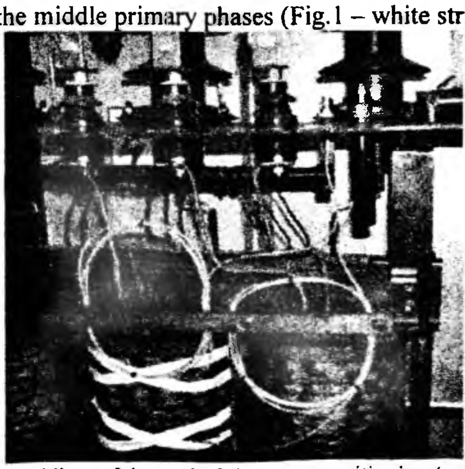
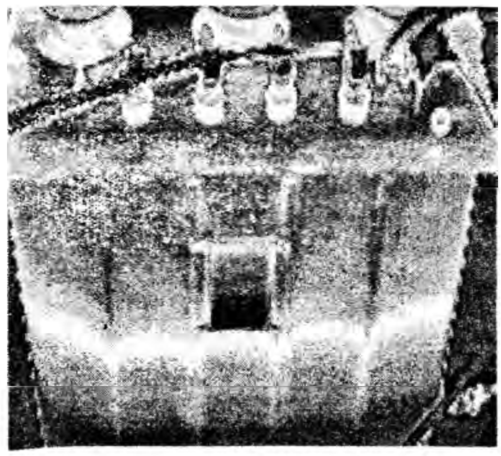


Fig.1. View of the optical detectors positioning (covered by white stripes)

Optical detectors were led out by special duct to the top part of the transformer's tank and from there they were led by two optical fibbers further to the measuring system NEOPTIX T, which was subsequently evaluating measured winding temperatures.

Transformer bushings and tank is monitored thermovision camera. In Fig.2 is vertical decrease of temperature for monitoring transformer tank. Thermal strain is the greatest in the top area of the transformer.



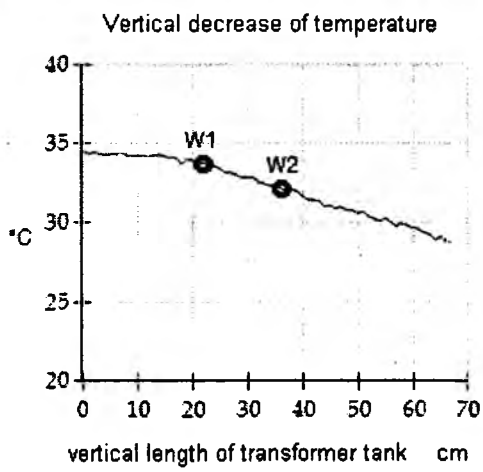


Fig.2. Decomposition temperature of monitored transformer 22/0,4 kV – 30% load