# Dynamic phase gratings in Yb-doped fibers with saturable absorption at 1064nm

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*Yb-doped optical fibers that are commonly employed in fiber lasers and amplifiers are shown to be attractive for applications in adaptive interferometers for detection of mechanical vibrations. We report two-wave mixing of phase modulated waves via dynamic population gratings in Yb-doped fibers. The unshifted gratings are characterized by submillisecond formation times and at wavelength of 1064 nm need cw recording light power of 1 - 10 mW scale. And what is important for the mentioned applications, the dynamic gratings are found to be predominantly of a phase type with an admixture of a significantly weaker amplitude component only.*

## Introduction

After the pioneer paper [1], the dynamic population gratings in Er -doped fibers attracted attention as promising nonlinear media with saturable absorption/gain for implementation of tunable narrowband optical filters and for realization of a single-frequency operation of standing-wave fiber lasers. In [2], such fibers have been proposed as a promising substitute of bulk photorefractive crystals in adaptive interferometers based on two-wave mixing (TWM) via dynamic Bragg gratings. Similar gratings recorded in Yb-doped fibers at wavelength $\lambda = 1064\,nm$ seem to be even more attractive for this application because of shorter spontaneous relaxation time of $Yb^{+3}$ meta-stable level ($\tau_0 < 1\,ms$) and because of availability of commercial Watt-scale cw lasers generating at this wavelength. Earlier only experiments on utilization of such dynamic fiber gratings in single-mode cw fiber lasers were reported. Here we present our recent results on investigation of the transient TWM via dynamic population gratings recorded in Yb-doped fibers at $\lambda = 1064\,nm$ [3].

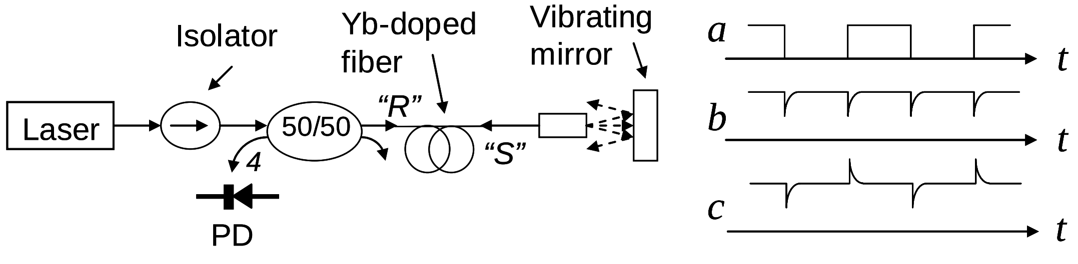


Fig.1. Experimental set up utilized in experiments on transient TWM in Yb-doped fibers and profiles of the rectangular modulating signal (a), and typical transient TWM responses expected for unshifted amplitude (b) and phase (c) dynamic gratings.

## Experimental setup

We utilized FNLD-50S-1064-DL14-BG single-mode single-frequency semiconductor laser ("Frankfurt Laser Company") with maximal output power about 50 mW at 1064 nm. The experiments were performed using configuration of the linear interferometer which can be considered as a prototype of an adaptive laser vibrometer, where periodic (rectangular in our case) phase modulation is introduced in one of the recording waves via piezoelectric modulator, which simulates the vibrating object (see Fig.1). The grating recording in this configuration is performed by two counter-propagating mutually coherent waves (R and S) with essentially different powers, and the output signal is detected using the weaker wave, which additionally increases the relative amplitude of the TWM response. The optical power detected with this interferometric configuration proves to be modulated because of fast periodic shift between the interference pattern and the inertial grating recorded in the doped fiber. The shape of the detected transient TWM signal strongly depends on type of the recorded dynamic grating [4]. For purely unshifted amplitude grating the TWM response is essentially of an even type (with all transient peaks of the same, negative sign), while for purely phase unshifted grating the response is of an odd type (every second peak is of the opposite sign). The complex grating, which possesses both the amplitude and phase component, is characterized by more complex response which can be presented as a sum of two above-mentioned typical responses [4]. In both cases the maximal amplitudes of the TWM peaks relate to the amplitudes of the corresponding grating components, while the characteristic relaxation time of the trailing edge of the TWM peaks corresponds to the grating relaxation time $\tau_g$.

In the presented experiment we used ~1.9 m long double-clad single-mode Yb-doped fiber with the core diameter of ~6 mm and with maximum absorption ~700 dB/m@975 nm. Direct measurements showed that the initial, not saturated optical density of the fiber at the recording wavelength 1064 nm was $\alpha_0 L \sim 0.8$. We utilized no optical pumping, which means that the population gratings were formed via local saturation of the fiber optical absorption.

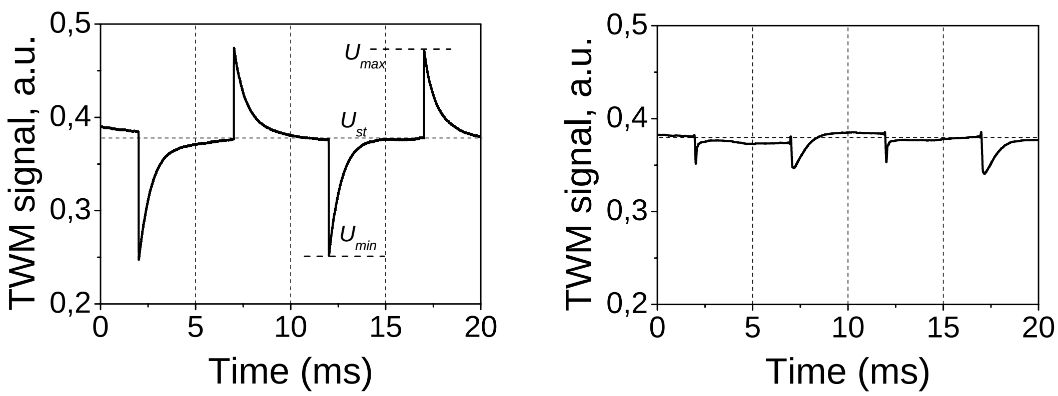


Fig.2. Typical transient TWM signals observed in under rectangular modulation with amplitude $U_{mod} \approx U_{\pi/2}$ (left) and $U_{mod} \approx U_{\pi}$ (right) with averaging over 512 oscilloscope traces.

## Results and discussion

Fig.2 presents typical profiles of the transient TWM signal, which appeared in response to the rectangular modulation voltage applied to the piezoelectric modulator. To record these signals we usually utilized averaging (typically over 512 oscilloscope traces), which was done to improve signal-to-noise ratio and to suppress slow fluctuations of the DC signal level and parasitic rectangular shape signals due to interference among the spurious reflections from different optical contacts of our fiber configuration.

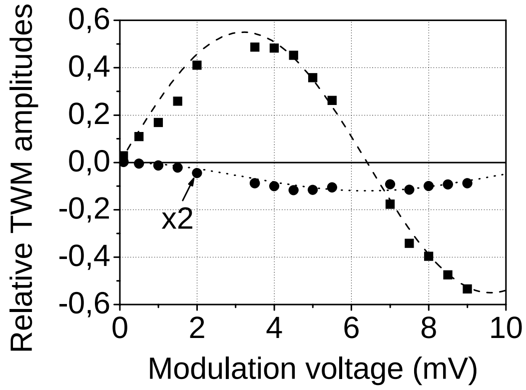


Fig.3. Experimental dependences of relative amplitudes of odd (squares) and even (circles) TWM signal components on $U_{mod}$ at $P_{in}$ = 5 mW. Solid lines present fitting by expected theoretical dependences.

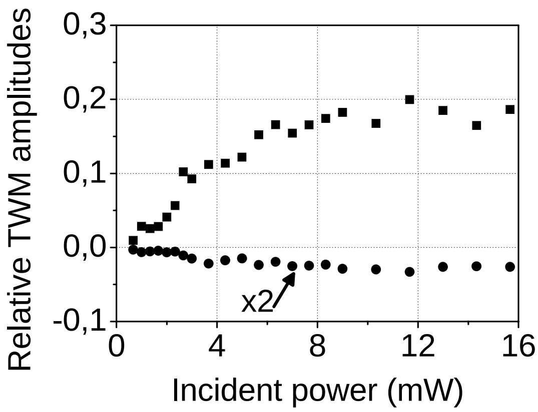


Fig.4. Experimental dependence of relative amplitude of the of odd (squares) and even (circles) TWM response components on input light power Pin ($U_{mod}$ = 1 $V_{p\text{-}p}$).

Essentially odd shape of the response implies dominating contribution of the phase component in the recorded dynamic grating [4], which seems to be reasonable for the recording wavelength located outside the maximum of $Yb^{+3}$ optical absorption. Experimentally observed dependence of the normalized TWM signal swing (evaluated as $\left(U_{\max} - U_{\min}\right)/U_{st}$ and relating to the phase grating) as a function of the modulation voltage amplitude (shown in Fig.3 by squares) follows the theoretically expected dependence $\propto \sin\left(\pi U_{mod}/U_{\pi}\right)$, with $U_{\pi} = 6.4\,V_{p-p}$. In its turn, the even component in the detected output signal, evaluated as $\left(U_{\max} + U_{\min}\right)/2U_{st} - 1$, which reflected contribution of the amplitude grating component to the TWM signal (shown in Fig.3 by circles), followed the theoretical dependence $\propto \left[1-\cos\left(\pi U_{\mathrm{mod}}/U_{\pi}\right)\right]/2$. Comparing the maximal values of these two TWM signal components one can conclude that the phase grating is approximately 10 times stronger than the amplitude one in this Yb-doped fiber. Evaluated in this way contributions of phase and of amplitude grating components in the transient TWM signal are also shown in Fig.4 as functions of the incident recording power. One can see that the detected TWM signals reach their maxima for the incident power about 12 mW. Characteristic time $\tau_g$ of the grating formation can be evaluated directly from the relaxation times of the TWM peaks presented in Fig.2. At low recording light power $\tau_g \approx 0.8\,ms$, which approximately corresponds to the spontaneous relaxation time of $Yb^{+3}$ meta-stable level. This leads us to conclusion that migration of the excited state among $Yb^{+3}$ ions does not play significant role in formation of the population grating in this case. With increasing recording power the grating formation time goes down and for the maximum incidence power used in our experiments (about 15 mW) was about 0.5 ms. These results correspond reasonably well with the theoretical prediction that the maximum TWM signal is typically reached for the recording power approximately equal to the saturation power of the fiber when the grating formation rate is approximately twice as large as that observed at low light level.

## Conclusion and acknowledgements

We have reported the results on investigation of the dynamic population gratings recorded at $\lambda = 1064\,nm$ in Yb-doped fibers with saturable absorption. The gratings formation time proved to be approximately one order of magnitude shorter and the recording cw light power approximately one order of magnitude larger than it is typically observed for similar population gratings in Er-doped fibers in spectral range 1480 – 1570 nm. The population gratings are shown to be predominantly of the phase type with the phase component one order of magnitude stronger than it is estimated from the fiber optical density and saturation power using simple two-level model. The last result is in a good agreement with our recent observations [5] explaining that a strong contribution to the phase component comes from UV transitions in the Yb-doped fiber.

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## References:

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