

# Polarization Self-Modulation Phenomenon in a Free Oscillated Nd:YAG Laser \*

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Polarization self-modulation effect in a free oscillated Nd:YAG laser is investigated after a quarter wave plate is introduced independently in the two positions of the cavity. As described in the previous experiments, the intensity components in the orthogonal directions are modulated with a period of the round-trip time or twice. Different pulse shapes reveal that the seed field from the spontaneous emission is not uniform and seems to be stochastic for each pulse.

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It is known that when a quarter wave plate (QWP) is inserted into the cavity, its birefringence effect complicates the dynamical behaviour of the laser. For a cw laser, the polarization self-modulation (PSM) phenomenon can be observed in the orthogonal directions with a degree of  $\pm 45^\circ$  with respect to the principal axes of the QWP.<sup>[1-9]</sup> Both the experimental results<sup>[1,7,9]</sup> and the theoretical analysis<sup>[1,11,12]</sup> revealed that the PSM effect results from the frequency shift between the eigenmodes in the principal axes of the QWP, which also corresponds to the coupling of the field components in the two directions at  $\pm 45^\circ$  with respect to the principal axes of the QWP after one round-trip time (RTT).<sup>[12]</sup>

In previous experiments, investigations on the PSM effect were limited on some cw lasers such as VS-CEL subject to an optical feedback passing through a QWP<sup>[2-9]</sup> or He-Ne laser, and laser diodes.<sup>[1]</sup> The polarization components of the output in the two directions mentioned above are completely modulated with a time shift of RTT and the oscillation period is two RTT. To the best of our knowledge, the dynamical behaviour of the laser pulses from a free oscillated laser with a QWP has not yet been investigated experimentally. The insertion of a QWP induces the periodic change of the polarization character of the field per two RTT, then this change will be amplified by the gain medium and distorted probably due to the unsymmetrical gain. In this Letter, we show our experimental results of a xenon lamp-pumped Nd:YAG laser with a QWP. The waveforms are all with a pulse envelope of  $3\ \mu s$  and are modulated at a high frequency of the longitudinal mode spacing or the half as displayed in cw lasers. A simple discussion for the dynamical

process is also presented.

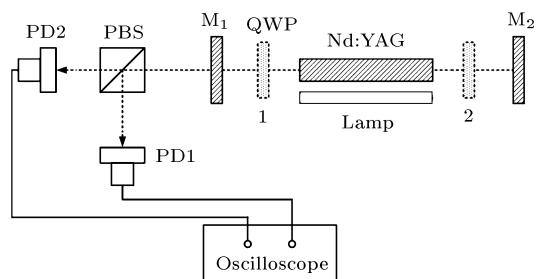


Fig. 1. Experimental setup.

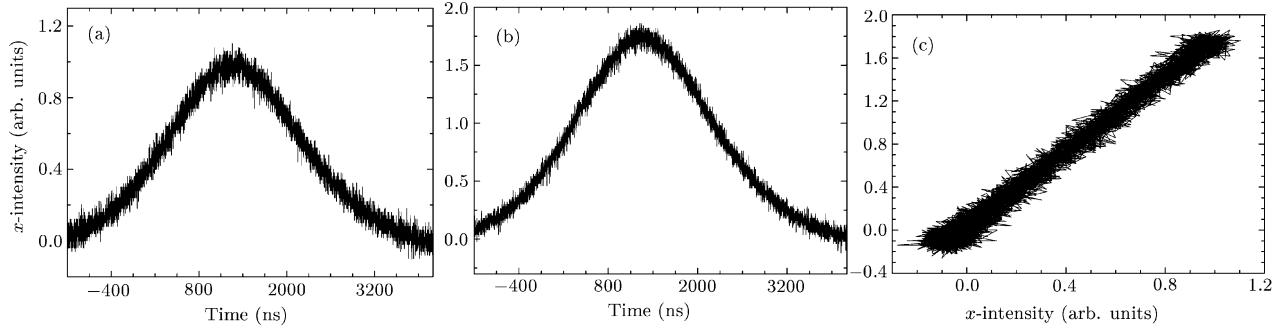
Figure 1 shows the experimental setup of a xenon lamp-pumped Nd:YAG laser with a QWP at two different positions and the measurement system for the intensity waveforms. A Nd:YAG crystal rod with a length of 120 mm and the pulsed xenon lamp are the gain medium and the pump source, respectively. The output mirror  $M_1$  is with a reflectance of 79% for  $1.064\ \mu m$  and the other mirror  $M_2$  with a reflectance of 100% for  $1.064\ \mu m$ , they are all plane mirrors. The pump is set to be about 1.2 times of the laser threshold. A polarization beam splitter (PBS) splits the light out of  $M_1$  into both photodetectors PD1 and PD2 (Thorlab D400FC), where the principal axes of the QWP are at  $\pm 45^\circ$  with respect to the two orthogonal polarization axes of the PBS, which are defined as the  $x$ - and  $y$ -directions. In our experiment, three types of intensity waveform of  $x$  and  $y$  components are measured by an oscilloscope (Tektronix TDS 3032B) with bandwidth of 300 MHz.

Firstly, as shown in Fig. 2, the waveforms without

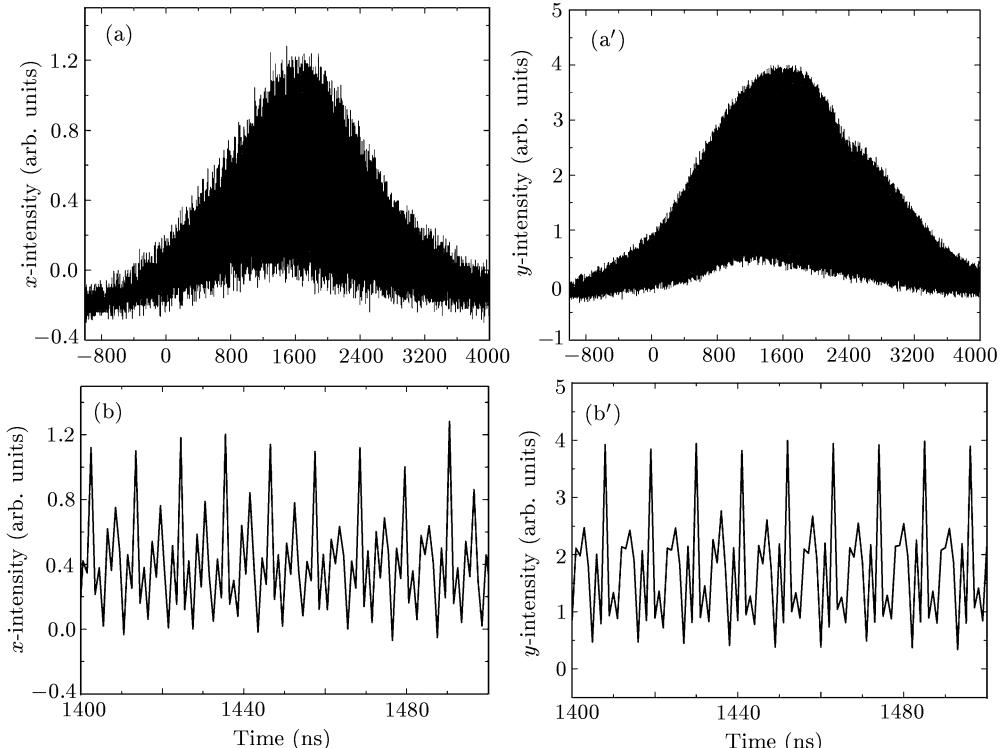
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**Fig. 2.** Intensity waveforms in the two orthogonal directions [(a) and (b)] without QWP, and (c) portrait of the two components.



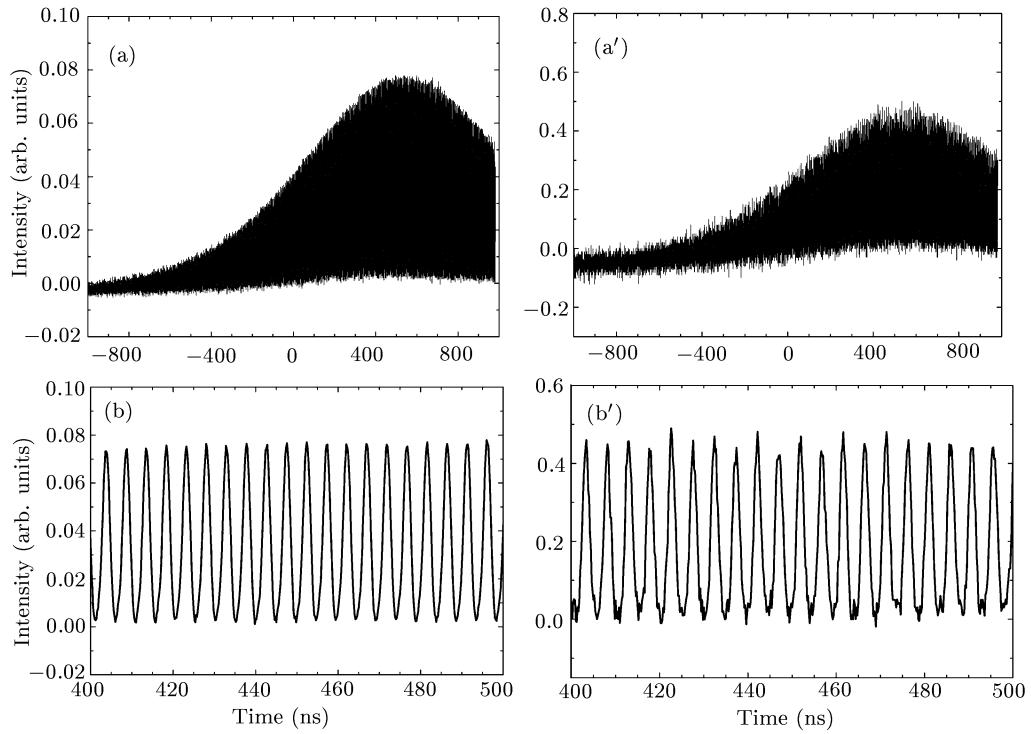
**Fig. 3.** Intensity waveforms of the two linearly polarized components located at with respect to the principal axes of the QWP at different times where the QWP is inserted between  $M_1$  and the gain medium.

QWP inside the cavity are observed. The optical cavity length is 810 mm. The laser pulses in the free oscillation state are all with a width of about 3  $\mu$ s and the waveforms of the two orthogonal components are similar to each other, as shown in Figs. 2(a) and 2(b), where a constant ratio exists between the intensity waveforms. Their polarization is linear<sup>[13]</sup> along a fixed direction for each pulse since the portrait of the two waveforms is a straight line, as shown in Fig. 2(c).

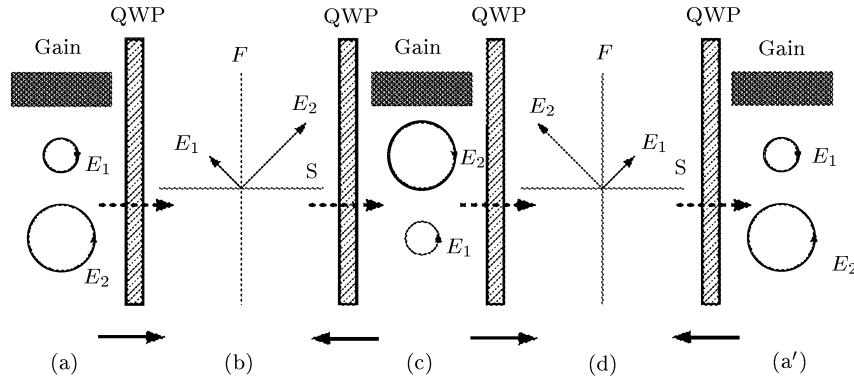
Secondly, a QWP is inserted at position 1 between the output mirror  $M_1$  and the gain medium. The waveforms of the two polarization components are usually with a period of twice the RTT and the corresponding envelopes are still with a width of 3  $\mu$ s, as shown in Figs. 3(a), 3(a'), 3(b), and 3(b'). A

shift of RTT is observed between the two waveforms in the time domain, as observed in the previous cw lasers.<sup>[1,2,7,9]</sup> The waveforms with a period of RTT can also be obtained.

Thirdly, the QWP is moved from position 1 to position 2 between the gain medium and the mirror  $M_2$ , the distance between the cavity mirrors is adjustable, and the optical length of the cavity is about 720 mm. The waveforms of the two components with a period of RTT are at the in-phase state. Figure 4 shows the intensity waveforms in the two orthogonal directions mentioned above. For other cavity lengths, the similar experimental results can be observed only with different RTT and different periodic waveforms since RTT is determined by cavity length.



**Fig. 4.** Intensity waveforms of the two linearly polarized components located at with respect to the principal axes of the QWP at different times where the QWP is inserted between the mirror  $M_2$  and the gain medium.



**Fig. 5.** Schematic diagram of polarization components in different regions and the transforms of the polarization states as the light fields pass through the quarter-wave plate for one period of PSM where F and S indicate the fast and slow axes of the QWP.

From the above experimental results, it is found that the waveform characteristics of PSM are similar to but more complex than those in the cw lasers.<sup>[1–6]</sup> In order to understand this dynamical procedure, the light field in the gain medium region is divided into the superposition of the left-hand and right-hand circularly polarized components with different amplitudes, as shown in Fig. 5(a). Having passed through QWP, the two circularly polarized components with different amplitudes transform into the two linearly polarized components in the two orthogonal directions as shown in Fig. 5(b). After the field passes through the QWP again, the two components return to the two circu-

larly polarized components with the same amplitudes but the opposite directions to those in Fig. 5(a). Difference of the two transforms induced by the QWP is attributed to the fact that light field passes through QWP forwards and backwards, respectively. After another round trip, the self-consistence of the vectorial field is realized, as shown in Figs. 5(c), 5(d), and 5(a'). Therefore, the period of the PSM corresponds to twice the RTT. The two output components in Fig. 4 are at in-phase state with a period of RTT. The anti-phase effect comes from the exchange of the amplitudes of the components per RTT, as revealed in Fig. 3. If the above two polarized components are with the same

amplitudes, the period of the waveforms is shortened to the round-trip time. On the other hand, if one of the two components is completely surpassed by the other one due to the their competition for population inversion, the output in Fig. 3 regenerates into the linearly polarized light with a periodically changed direction, as revealed in the cw lasers with a QWP.

In summary, PSM effect have been observed in a free oscillated Nd:YAG laser after a QWP is inserted in the cavity. Differences among the PSM waveform shapes originate from the stochastic spontaneous emission for each free oscillated pulse. The presented results show that the self-consistence of vectorial light field corresponds to two RTTs of the cavity with a QWP.

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