A NOVEL MODE-LOCKING TECHNIQUE

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I. INTRODUCTION

A feedback controlled mode-locking in Nd: YAG oscillator has been successfully demonstrated by a novel mode-locking technique. The ultrafast response time of the switch without any avalanche is essential to the mode-locking. For photoconductors in common use, the intrinsic monocrystalline silicon and the GaAs are very familiar to us. Although Si has very fast response and high sensitivity, its dark resistance is not large enough (only about $(20 - 30) \times 10^3\ \Omega$) to stand very high voltage. The Cr-doped GaAs has fast response time and high sensitivity as well as large dark resistance which could be generally up to $10^9\ \Omega$. So it can be operated under high voltage for a long time. On the basis of its characteristic of the decrease of resistance with the increase of irradiation, we have designed a positive feedback controlled network which can generate high feedback voltage (more than 1 kV). The mode-locked pulse with the duration of 100 ps has been obtained. The mode-locked pulse trains are very stable. The following sections are devoted to the principle, the experimental results and a discussion.

II. PRINCIPLE

The relationship between the conductivity $G(t)$ and resistivity R of GaAs photoconductive switch is $G(t) = R^{-1}$. The conductivity G is inversely proportional to the irradiation intensity. As soon as a laser pulse irradiates the GaAs photoconductive switch, its resistance will be reduced rapidly. Fig. 1 shows that a high feedback voltage V_R from the resistance R_1 drives the PC, then the effective voltage V_{eff} on the PC is $V_{eff} = V_b - V_R$ (V_b is a bias-voltage on the PC). It can be seen that the PC, polarizer and GaAs photoconductive switch form a positive feedback controlled network. Receiving the polarized light reflected from the polarizer, the GaAs photoconductive switch combined with the resistance R_1 converts the light signal into a feedback voltage V_R via the PC. The higher the intensity in the cavity, the higher the intensity of light irradiating on the GaAs photoconductive switch. The feedback voltage on the PC is higher, and the effective voltage V_{eff} will be lower. Thus the transmission of the PC switch will increase, and the loss of the cavity will be reduced. It means that the net gain increases. As a result, the increment of the biggest initial pulse is much faster than those of any other pulses. In contrast, the weaker pulse will be decayed out. This mechanism is similar to that of saturable absorbers. But its amplitude discrimination is much greater than that of saturable absorbers. The positive feedback network provides an amplitude discriminability, the gain saturation strengthens the discriminability. If the laser pulse syncronizes with the positive feedback voltage on the PC, the oscillator can generate ideal mode-locked pulses. The main difference between the two mechanisms could be shown as follows.

The transmission of the saturable absorber[1] is

$$T_s = \exp(-k) = \exp\left(\frac{-k_0}{1+\frac{I(t)}{I_s}}\right), \tag{1}$$

where, k_0 is the unbleached absorption coefficient, I_s is the dye saturation intensity and $I(t)$ is the intensity in the cavity.

The transmission of the PC switch in the positive feedback controlled network is

$$T_p = \cos^2\left[\frac{\pi}{2}\,\frac{V_{eff}}{V_0}\right] = \cos^2\left[\frac{\pi}{2}\,\frac{(V_b - V_R)}{V_0}\right], \tag{2}$$

where, V_0 is the quarter-wave bias-voltage on the PC.

It can be seen from Eqs. (1) and (2) that the transmission of the saturable absorber is proportional to one power of the intensity in the cavity at the beginning of forming the mode-locked pulses, but the transmittance of the positive feedback network is proportional to the square of the intensity. For this reason, the discriminability of the feedback network is much stronger than that of the saturable absorber, the probability of mode-locking of the feedback network is much higher and its output is also much stabler. In addition, the main elements in this network such as the PC, polarizer and GaAs photoconductor, are all endurable, while the saturable absorber has an intrinsic chemical unsteadiness. Compared with the passive mode-locking, the feedback controlled mode-locking is much more reliable and convenient.

III. Experimental Results and Discussion

A schematic arrangement of the laser oscillator is shown in Fig. 1. The cavity length is 1.5 m, the gain medium is Nd: YAG with diameter of 4 mm and length of 50 mm, which is located in a single-elliptical glass pump cavity. The pump cavity is cooled by cycling water. The lamp is a xenon one with diameter of 6 mm and length of 70 mm. The voltages applied on the PC and GaAs photoconductor switch are 2000 V. KD*P crystal is close to the reflecting mirror. The pump rate is about 1.10.

The mode-locked pulses with probability of about 100% have been achieved. The energy instability of the pulse train is ±5%. The waveforms are displayed on a high speed oscilloscope (see Fig. 2). The pulse width is measured by using Two-Photon Fluorescence

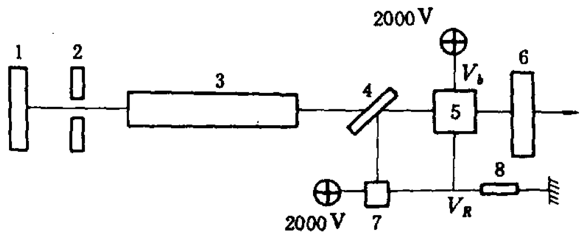

Fig. 1. Arrangement of the positive feedback controlled mode-locking oscillator, with the cavity length of 1.5 m.
1, Total reflector; 2, aperture (Φ1 mm); 3, Nd: YAG rod (Φ4 × 50 mm); 4, polarizer; 5, pocket cell; 6, output mirrior (T=50%); 7, GaAs switch; 8, resistor R_l.

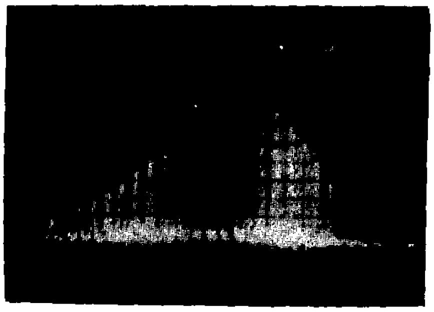

Fig.2. The mode-locking train (time scale: 10 ns/ div.).

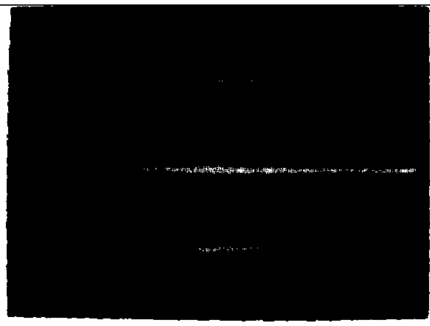

Fig.3. TPF pattern (pulse duration: 100 ps).

(TPF) method. The TPF cell is 10 cm long. The full width at half maximum of the pulse (FWHM) is about 100 ps (< 100 ps, see Fig. 3). The experiment shows that it is not necessary to precisely synchronizing the pulses with the feedback controlled voltage on the PC, while the mode-locked region needs reaching about 1 cm. This is because the synchronization is only single time, different from the acoustooptic mode-locking which has an "accumulation effect". So the demanded synchronizing precision becomes very low. It is very easy to change the feedback voltage by varying the voltage on the PC. The initial feedback voltage has a very important influence on the mode-locking probability. Its action is similar to the unbleached concentration of dyes used in positive mode-locked laser. So this technique is very convenient to manipulate. One can easily obtain the ideal mode-locked pulses by changing the voltage on the GaAs switch. Compared with the acoustooptic mode-locked modulator, the positive feedback network has much deeper modulating depth. For example, an acoustooptic mode-locked modulator with frequency of 50 MHz can only generate mode-locked pulses modulated by a sine function whose modulating period is only 10 ns, and generally the modulating depth does not exceed 50% (1.06 μm). It is easy for the modulating depth to exceed 50% with this new technique, and the width of the feedback voltage pulse is less than 100 ps. Hence, the positive feedback controlled mode-locked technique could produce much higher S/ N ratio and much stabler mode-locked pulses.

IV. Conclusion

Athough the preliminary experimental results are not very satisfiable for the wide pulse duration, the feedback controlled mode-locking is a perspective novel technique. One reason for limiting the pulse to be narrow is the influences of the remained F-P effect of the KD*P crystal and the glass plate of the window. Our work is in the process of further developing this technique.

Reference

[1] Glenn, William H., *IEEE J. Quantum Electron.*, **QE-11** (1975), 1:8.