Laser resonator of novel configuration applicable to efficient electro-optical countermeasure

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Abstract: Based on the phenomena that electro-optical devices with "cat eye effect" can reflect input light beam exactly back along the direction the beam incidents, a resonator of novel configuration was formed by utilizing the "cat eye" system as an equivalent resonant mirror of laser. The equivalent reflectivity of "cat eye system" was defined to describe the ability of reflecting input light exactly backward. Laser oscillation was achieved by pumping a Nd:YAG rod located between a corner cube prism and a cat eye system. These properties make it possible to be applied in electro-optical countermeasures.

Key words: cat-eye effect; electro-optical countermeasure; laser oscillator; corner cube prism
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可应用于高效光电对抗的新颖结构激光谐振腔

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摘 要: 光电设备具备的“猫眼效应”可以将入射的光线沿原路反射,基于这一现象,可以将该光学系统作为激光器的一个腔镜构成激光谐振腔。文中计算了“猫眼效应”光学系统作为激光器腔镜的等效反射率。实验中用灯泵 Nd:YAG 激光器,角锥棱镜和猫眼光学系统搭建了免调激光谐振腔,获得了激光振荡,激光起振的同时,在猫眼光学系统焦平面不同材质介质上留下烧痕。这种将对方光学系统作为激光器的腔镜,激光起振即摧毁的构成,可应用于光电对抗之中实现高效对抗。

关键词: 猫眼效应; 光电对抗; 激光谐振腔; 角锥棱镜

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0 Introduction

In recent years, applications of lasers in electro-optical systems advanced the technology of electro-optical countermeasure significantly. Cat eye effect is a common property of most electro-optical devices and this property has been utilized efficiently in electro-optical countermeasures. Cat eye effect and its applications have been extensively studied by many research teams, but mostly limited to target recognition and positioning[1-9]. In this paper, a new configuration of electro-optical countermeasure method utilizing cat eye effect is presented.

By this new means, an electro-optical device with cat eye effect is applied in laser oscillator to be a resonant mirror to establish laser oscillation. Meanwhile, as the laser oscillation is established, high intensity of laser beam focused at optical sensor (or other medium) at the focus plane of the electro-optical device will almost unavoidably destroy the device. The new concept of electro-optical countermeasure method is proved both in theory and in experiment.

1 Theoretical basis of cat eye effect utilized in laser oscillators

The principal set-up of a laser oscillator is plotted in Fig.1. Light is amplified by induced

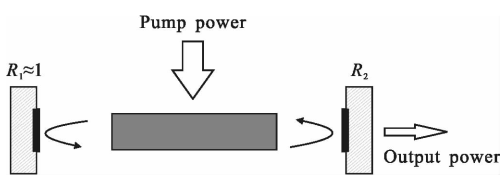


Fig.1 Schematic of a laser oscillator set-up

emission in an active medium. The beam bounces forth and back between the two mirrors of an optical resonator. On-set of laser oscillation requires a gain factor exceeding the total losses per round trip (threshold condition)[10]:

$$G_0RV>1 \tag{1}$$

wherein G_0 is small-signal gain factor for the intensities, $R=\sqrt{R_1R_2}$ is average reflection factor of the mirrors, V is internal loss factor of the resonator.

In common, R_1 and R_2 with high reflectivity (or partial reflectivity for laser output) are mirrors with planar or spherical surfaces for efficient reflection of laser beam and laser output. But, other optical components such as corner cube prisms or even cat eye retro-reflectors also with high reflection factor can be applied in laser resonators. Electro-optical devices with cat eye effect are one sample of them.

In most electro-optical devices, there is a common feature so called cat eye effect. With reflective medium, such as optical sensor or cross-reticle, placed at the focal plane of a focal lens system, these structures can reflect the input beam exactly backward along the direction it incidents the electro-optical system and this phenomenon was called cat eye effect. While being applied in laser resonator as R_2 in Fig.1, once the gain factor exceeds the total losses, the laser oscillators can be established. Because the oscillated laser beam in this structure is focused on the medium at the focal plane of the focal lens system, the light density is very high at the focus point. As in these electro-optical devices, mostly optical sensors are commonly placed at the focus plane to detect optical signal. Extremely high light density will unavoidably damage the sensor, at least the optical surface of the sensor.

The electro-optical devices, while being applied as a resonator mirror R_2 (or R_1) in laser oscillators shown in Fig.2, the equivalent reflectivity is deduced as following[11].

A electro-optical device with cat eye effect can be simplified and modeled as shown in Fig.2. The focal lens F is the entrance aperture of the device, T is the reflective medium, mostly optical sensor of the device, located at the focal plane of F, and f is focal length of F. When a pencil of beam incidents into the optical system, it will be focused to a small spot at the reflective medium T, and, reflected. The reflected beam from T will pass through the focal lens and propagate along the direction the beam incidents and the cat eye phenomenon can be observed. In order to quantitatively describe the reflecting ability of a cat eye system, the equivalent reflectivity R_2 is introduced.

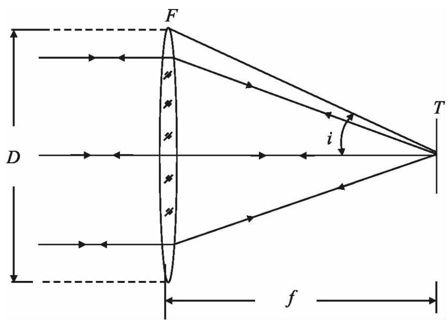


Fig.2 Schematic diagram of the cat eye effect system

Given that T with reflectivity ρ_c is subject to Lamber′s law, D is the diameter of pupil F, f is focal length, considering a light beam with intensity φ_i incident into the cat eye system from the pupil F, then focused onto T which reflect the beam into a hemisphere of 2π steradians uniformly, only the radiation into the steradian Ω subtended by the pupil F can be reflected back. The reflected beam intensity φ_o can be given:

$$\varphi_o=\rho_c\varphi_i\int_\Omega \cos i\mathrm{d}\Omega=2\pi\rho_c\varphi_i\int_0^i \cos i\cdot\sin i\mathrm{d}i=\pi\rho_c\varphi_i\sin^2 i \tag{2}$$

Where $\tan i=D/2f$ is defined as the relative aperture of the pupil as shown in Fig.2. The equivalent reflectivity is:

$$R_2=\frac{\varphi_o}{\varphi_i}=\pi\rho_c\sin^2\left(\arctan\frac{D}{2f}\right) \tag{3}$$

While the relative aperture of the optical system is with a relatively small value, $\sin i\approx\tan i=D/2f$ can be given, then:

$$R_2=\frac{\phi_o}{\phi_i}=\pi\rho_c\left(\frac{d}{f}\right)^2 \tag{4}$$

From this equation, the equivalent reflectivity R_2 is determined by the reflectivity of the focus plane medium and the relative aperture of the optical system, we can calculate the equivalent reflectivity of cat eye divices when they are utilized as resonant mirrors.

If the cavity length is L, l is the length of laser rod and $L>>l$, then the loss in this resonator can be expressed as:

$$\delta=\alpha_1 l+\alpha_2 L+\delta_x+\delta_d(L) \tag{5}$$

Where α_1, α_2 are the attenuation in the gain medium and atmosphere, $\delta_x=(1/2)\ln\ (1/R_1R_2)$ is the loss at the two resonator mirrors, R_1, R_2 are the reflectivity at mirror A and the cat eye device. δ_d is the diffraction loss expressed as a function of L[12]:

$$\delta_d(L)=0.303\sqrt{\left(\frac{1}{N}\right)^3}\frac{1+\frac{\beta}{M}}{\left[\left(1+\frac{\beta}{M}\right)^2+\left(\frac{\beta}{M}\right)^2\right]^2} \tag{6}$$

Where $N=a^2/\lambda L$ is the Fresnel coefficient, a is the diameter of resonator mirrors and $\beta=0.824$, $M=(8\pi N)^{1/2}$。

When parameters except for L in Eqs.(5) and (6) are constants, the cavity loss $\delta=\alpha_1 l+\alpha_2 L+\delta_x+\delta_d(L)$ is a function of L.

In order to achieve laser oscillation in this resonator, the inversion population in the gain medium must be pumped above the threshold, which means energy stored into the gain medium should be above the threshold[13]:

$$E_{\mathrm{th}}=\frac{Ah\nu}{\sigma\eta_p}\cdot\delta \tag{7}$$

Where A is the area of cross section of the gain medium, σ is the stimulated emission cross section, $h\nu$ is photon energy of the absorbed light, and η_p is the pumping efficiency.

2 Experiment

A schematic drawing of the experimental setup is shown in Fig.3. A Nd:YAG rod of $\phi6\times100$ mm is used as active medium, Xe-lamp pumped. The cat eye effects is simulated by a focus lens with D=80 mm, f=150 mm. A corner cube prism is applied as one mirror of the laser oscillator with high reflectivity and needless of adjustment. Different matters were used at focus plane as reflective medium.

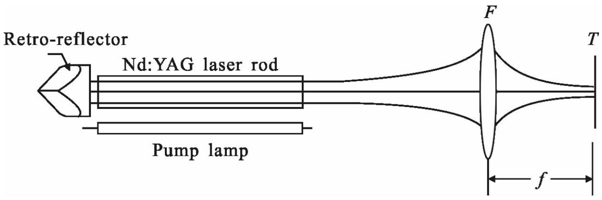
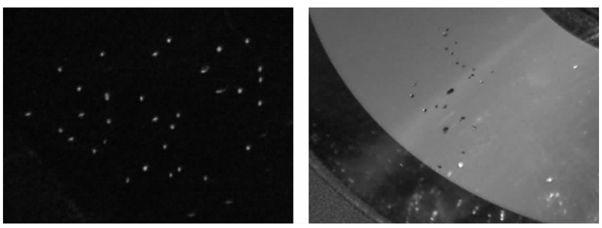


Fig.3 Schematic diagram of the laser resonator with cat eye effect device

Approximately given the reflectivity of reflect medium $\rho_c \approx 0.5$, the equivalent reflectivity of the cat eye effect system applied in laser was:

$$R_2=\frac{\varphi_o}{\varphi_i}=\pi\rho_c\left(\frac{d}{f}\right)^2=\pi\times0.5\times\left(\frac{40}{150}\right)^2\approx11\% \quad (8)$$

In the experiment, the distance between the focus lens and the retro-reflector is up to 4.85 m in laboratory. With Xe-lamp pumped, the laser oscillation was established and on the mediums at focus plane, the laser focus spots were observed, as shown in Fig.4.



(a) Black photo-paper (b) CD-ROM

Fig.4 Experimental results

The laser oscilloscope traces were also recorded, as shown in Fig.5.

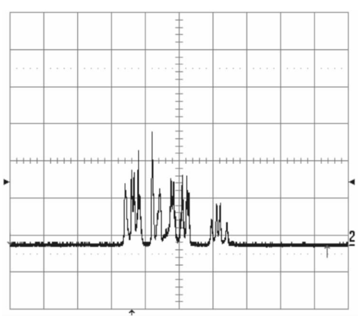


Fig.5 Oscilloscope traces of laser oscillations in the experiment

3 Conclusion

Electro-optical devices with cat eye effect can be applied as a mirror of laser oscillator to get laser oscillation. While the laser oscillation is established, the medium at the focus plane of the electro-optical device will almost unavoidably be damaged due to extremely high intensity of the focused laser point on it. The process is analyzed theoretically and the phenomena was experimentally observed. For optical countermeasures takes place in a long range between fighters, the parameters needed to establish laser oscillation should be considered carefully, and this should be discussed later.

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