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# Relaxation Oscillation in the Excimer Medium

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**Abstract**

Relaxation Oscillation of the light intensity in the rare gas halide excimer medium is described. The high-pressure mixture consists of rare gas, halogen and appropriate buffer gas. An argon laser-beam was employed to probe the active medium. We derived a differential equation describing the change of the photon density with a perturbation method. The relaxation oscillation period calculated is in agreement with the experimental value.

**Key words:** relaxation oscillation; excimer medium; rare gas halide; perturbation method; period.

## Introduction

Because of their numerous applications, there are considerabale interest in excimer laser system[1,2]. In order to establish optimum operating characteristics of such lasers, it is important to distinguish and explain various phenomena in the active medium. This work discussed the relaxation oscillation observed in the excimer medium pumped by electron-beam.

## Experimental Configuration

The experimental configuration used for the measurements is shown in Fig. 1. An argon laser beam was used to probe the active medium (at 514.5 nm). Two apertures were placed after the cell to reduce fluorescence in the probe direction. The 7 m folded optical path to the detection equipment located in a Faraday screened cage also reduced fluorescence effects. Neutral density filter were used to reduce the input light level to the photomultiplier (PMT) to avoid saturation. A 1/4 m. Jarrel-Ash monochromator or a narrow band interference filter provided spectral selectivity. The PMT (RCA C31000B) output was digitized by the transient digitizer (R7912)

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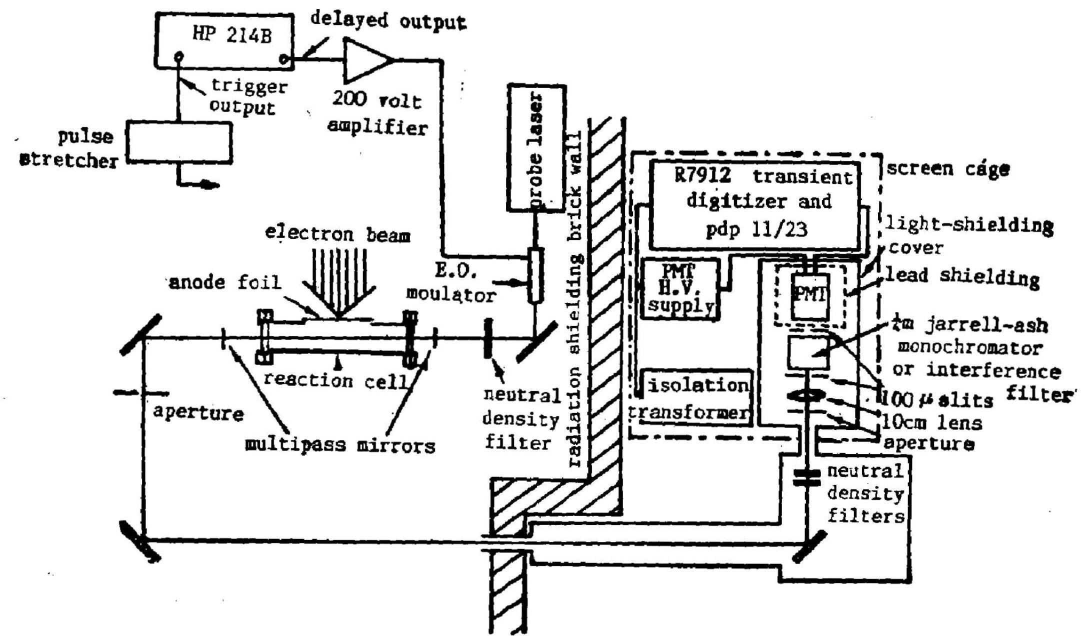


Fig. 1 Experimental Configuration for Probe Laser Gain Measurements

and stored by the computer (PDP 11/23) for later data reduction.

The apparatus required to produce a pulsed probe beam is illustrated in Fig. 1. It consists of a pulse generator, a high voltage pulse amplifier, and an electro-optic (E-O) modulator. Using a polarizer with a 1000:1 extinction coefficient, a high peak output could be produced while maintaining a very low DC baseline. The pulse width could be adjusted to produce output which were constant on the E-beam current time scale.

However, several problems were encountered with this approach. Therefore at present the modulator was not used during these measurements.

Careful shielding of the modulator and PMT will be required before the pulsed method may be used.

Signal level of ~20 mV were used during the DC probe beam measurements. Careful electrical and X-ray shielding of the detection apparatus in particular the PMT, resulted in noise levels of 2~4 mV with signal levels of 10~40 mV.

## Relaxation Oscillation

An interesting feature is the relaxation oscillation of the optical field intensity seen in the gain data (Fig. 2). The relaxation oscillation indicates interaction between the light field and the excited medium. The basic process roughly is in the following.

An increase in the field intensity causes a reduction in the popu-lation inversion due to the increased rate of stimulated transitions. This causes a reduction in the gain which in turn tends to decrease the field intensity.

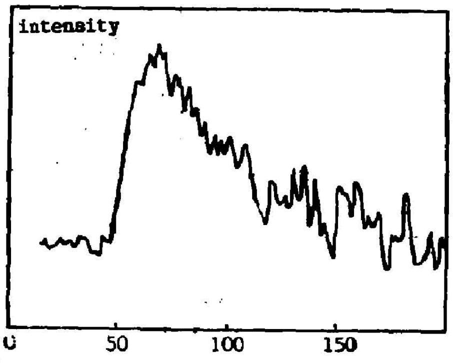

Fig. 2 Relaxation Oscillation of Optical Field in the Cell

In the theoretic modeling of the phenomenon, we assume an ideal homogeneously broadened laser with a four-level system and lower laser level is always empty, which is a quite good model for the excimer medium with high pressure. (~6 atm.)[3] Because the excited state of excimer lives for a reasonable length of time, say, 10~20 nsec for dimers and $10^3$ nsec for trimers [4], whereas the lower state (the disinterested neutrals) lives for only the time it takes the two or three atoms to fly apart, $\sim 10^{-3}$ nsec. That is an acceptable approximation to zero.

Using the perturbation method, i.e. we consider the behavior of small perturbation from equilibrium (steady-state) and according to the standard preocess of this methode, a differential equation describing the change of the photon density $n_1$ in the cell can be derived as follows

$$\ddot{n}_1 + B\dot{n}_1 + Cn_1 = D \quad (1)$$

here $D$——the driving function.

When $D=0$, in the analogy to a resonant RLC circuit, equivalently, the equation is identical in form to that describing a damped nondriven harmonic oscillator, and

$B = p/\tau$——the damped factor,

$C = (p-1)/(\tau \cdot t)$——the frequency factor,

$p = P/P_{threshold}$——the pumping factor, it is equal to the ratio of the unsaturated gain to the saturated gain.

$\tau$——the atomic lifetime.

$t$——the lifetime of the photon in the cell,

$P$——the pumping rate.

The system clearly has an exponentially damped sinusoidal response. If we assume that the small quantity $n_1(t)$ varies as $e^{at}$. We obtain

$$a^2 + Ba + C = 0 \quad (2)$$

$$a = a_1,\ a_2 = -B/2 \pm [(B/2)^2 - C]^{1/2} \quad (3)$$

In most gas lasers, to take care of the nonspiking case, the atomic lifetime $\tau$ and the lifetime of the photon in the cavity $t$ can be of the same order of magnitude. In fact the $t$ is somewhat longer and the laser is not too far above threshold, so that $C$ is less than $(B/2)^2$. The two roots of (2) are then $a_1\approx -B= -p/\tau$, $a_2\approx -C/B= -(p-1)/(pt)$. The transient response of the oscillating laser to any sort of fluctuation in this limit has two exponentially decaying roots, one of which corresponds to a net population repumping rate $p/\tau$, whereas the other corresponds to a net cavity build-up rate of $(p-1)/(pt)$. The system is overdamped, so that any perturbation die out in a double exponential form rather than an oscillatory fashion with time constants corresponding briefly to the atomic and the photon lifetimes. When a laser in this kind is suddenly turned on, the laser oscillation will build up and converge toward the steady-state level with small or no overshoot, at least without the sort of considerable relaxation oscillations associated with spiking kind of lasers.

The alternative case, which is featur of most solid-state and the excimer laser,[5] has whenever the atomic lifetime $\tau$ is very much longer compared to the lifetime of the photon in the cavity $t$. In this case the roots for the transient response of the system can be written in the form

$$a_1,\ a_2\approx -B/2\pm i[C-(B/2)^2]^{1/2}\equiv -B/2\pm i(2\pi/T)$$

and

$$C\gg (B/2)^2$$

The relaxation oscillation behavior dies out with the decay rate $(B/2)$. So that period of the small-signal relaxation oscillation $T$ is obtained

$$T\approx 2\pi\cdot[(\tau\cdot t)/(p-1)]^{1/2}$$

Also the population inversion will have similar damped sinusoidal fluctuation about its steady-state value.

If we take typical values for say, $Xe_2Cl$ laser mixture gas medium pumped to $\sim$50 above threshold and $\tau\sim 10^2$ ns. $t\sim 0.2$ ns for our cavity cell. We find a typical relaxation oscillation period of

$$T_{Xe_2Cl}=2\pi\times[10^2\times 0.2/(50-1)]^{1/2}\,\text{ns}\approx 4\,\text{ns}$$

This value agrees with the order of the experimental value from Fig. 2.

The fluctuation in the power output is thus a damped sinusoid with the damping rate $(B/2)$ and the oscillation period $T$ decreasing with excess pumping. The $T$ for the large-amplitude spikes in the strong spiking regime will be less than the small-amplitude relaxation oscillation period but not more than a factor of 3. The damping rate for the large-amplitude spikes will also be different. However, at least the $T$ and $(B/2)$ give a general indication of the resonant period and damping rate of the light intensity even for large-amplitude fluctuations. Indeed measurements of $T$ have sometimes been used as a way to find values for the parameters $p$ or $t$.

While some lasers display the damped sinusoidal fluctuation of intensity described above, in many other laser systems the fluctuation is undamped. The undamped relaxation oscillation observed in many situations may be understood by considering (1). Undamped oscillation is possible when the driving function $D\neq 0$ in (1) (i.e.

the "oscillator" is driven). In this situation, the equation is identical in form to that describing a undamped driven harmonic oscillator or, equivalently, a resonant RLC circuit with a driving source $V(t)$[6].

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# 准分子介质中的弛豫振荡


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## 提　　要


本文描述了稀有气体卤化物准分子介质中光强的弛豫振荡，使用的高压混合气体由稀有气体。卤素和相应地缓冲(稀有)气体所组成。借助氩离子激光束(514.5nm)探测激活介质，测得三原子准分子 $Xe_2Cl$ 的弛豫振荡周期值为 4ns 左右。系统用相对论强电子束进行泵浦。

在对准分子介质的光学增益观测中，发现了光场强度弛豫振荡的有趣现象。这种振荡表明了光强与被激励介质间的相互作用。本文首次描述了准分子介质中的这种振荡，其物理学机制可以认为是：光强增加导致受激发射速率增加使得粒子数反转下降，这就引起光学增益减小，而光学增益的减小反过来又导致光强的减弱。

我们假设，高压混合气体被电子束泵浦后形成均匀加宽的四能级系统，而激光下能级是空的。利用微扰方法，建立起了描述腔内光子数密度变化 $n_1$ 的微分方程如下：$\ddot{n}_1+B\dot{n}_1+Cn_1=D$。进一步，类比无线电技术中 $RLC$ 线路理论，可以得到弛豫振荡的周期 $T$ 为 $T=2\pi[t\cdot\tau/(p-1)]^{1/2}$。其中，$p$——是泵浦函数，$t$——是腔内光子寿命，$\tau$——是除受激发射之外，其他一切因素造成的激发态寿命。由这一公式计算出的周期 $T$ 理论值和实验中观测到的值基本上是一致的。这样，反过来就可由测量弛豫振荡周期，去确定泵浦函数或原子寿命，并和其他方法相佐证。



关键词：弛豫振荡；准分子介质；稀有气体卤化物；微扰法；周期。



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