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by

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STIMULATED ROTATIONAL RAMAN SCATTERING OF N_2 IN THE ATMOSPHERE /679*

Song Ruhua Yue Shixiao

ABSTRACT

This article generally describes stimulated rotational Raman scattering (SRRS) of N_2 in the atmosphere. It summarizes theoretical and experimental research work in the field in question in recent years. In conjunction with this, it carries out discussions on a number of problems which still have not been resolved up to now.

In 1962, E.L. Woodbury and others [1] first observed in liquids stimulated Raman scattering (SRS). After this, related theoretical and experimental work made very great progress [2,3]. However, right along, it was limited to research carried out on solids, liquids, and high pressure gases, and, with regard to normal pressure as well as low pressure gases (such as the atmosphere), by contrast, due to SRS gain being very small, there was no consideration given to it. In recent years, due to the development of strong laser technology to act as laser weapons, people began to pay attention to laser SRS in normal pressure gases. In particular, due to the fact that N_2 SRRS is one of the nonlinear effects in the atmosphere where it is already known that threshold power values are the lowest, as a result, in depth study was entered into of the important significance it possesses.

In 1978, V.S. Averbakh and others [4] analyzed N_2 stimulated Raman scattering and stimulated vibrational Raman scattering (SVRS). Their theoretical analysis and experimental results clearly showed that, in areas with gas pressure $P > 10$ atm, SVRS was dominant, correspondingly suppressing SRRS. However, when

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

gas pressure $P < 10$ atm, SRRS clearly increased in strength. SVRS correspondingly weakened. In particular, when $P < 2$ atm, then SRRS threshold values were clearly lower than SVRS. Moreover, in the vicinity of $P - 1$ atm, SVRS had clearly been suppressed. What is important at this time is that SRRS takes the leading role. Corresponding gas pressure and SRS gain coefficient relationships are as shown in Fig.1. From the Fig., it is possible to know that, in the atmosphere (in particular, the upper atmosphere), the influence produced on the nature of the substance of strong laser beams by atmospheric propagation is N_2 SRRS. Moreover, the appearance of Raman light will produce very large influences on original beam strength distributions as well as emission angles, thus lowering laser weapon attack capabilities. Averbakh and others also discovered that, in N_2 rotational transitions, S(8) first reaches threshold value light strength. Next is S(10) and S(6), etc.

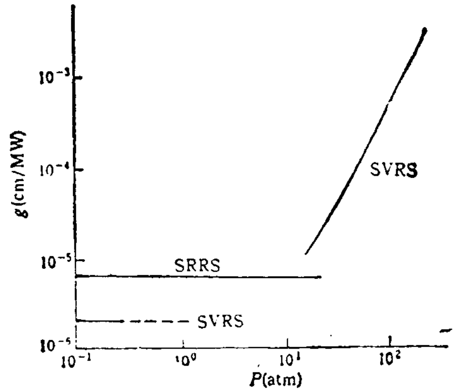

Fig.1 Relationship Curves Associated with Gas Pressure P and Gain Coefficients g (SRRS and SVRS Simultaneously Exist)

M. Rokni and others [5] analyzed SRRS associated with two types of important constituents in the atmosphere—N_2 and O_2. Theoretical results clearly showed that, at normal temperature and pressure (or low pressure), N_2 stable state SRRS threshold values are lower than O_2 stable state threshold values. As a result, under normal atmospheric conditions, N_2 S(8) rotational transitions possess the lowest threshold values. This influences the chief factors associated with strong laser atmospheric propagation properties. Going a step further, Rokni and others analyzed gains and threshold value strengths in situations where $N_2S(8)$ transitions were associated with different Fresnel numbers and pump wave lengths (see Table 1 and Fig.2). Results clearly showed that threshold value strengths P_c follow increases in F (or decreases in λ_p) and decrease. Because of this, it is possible to see actual requirements acting as the basis for selecting relevant parameters.

Due to the fact that strong lasers acting as weapons require up and down transmission perpendicular to the ground surface, the result is a need to consider the influences of atmospheric density following changes in altitude (sea level is the zero point) on parameters related to $N_2S(8)$ SRRS. G.C. Herring and others [6] made use of standard atmospheric models and discussed relationships associated with changes in N_2 S(8) SRRS gains following changes in altitude. As in Fig.3, beginning from sea level and up to locations with vertical altitudes of approximately 20km, gains gradually increase. Following that, along with continuing increases in altitude, gains begin to drop. At 80km locations, gains drop almost to zero. The result is that strong laser propagation at high altitudes is extremely beneficial to guaranteeing beam quality. Of course, here there is no consideration of other optical effects associated with upper atmospheric space (for example, turbulence, and so on). Actual situations will be much more complicated.

TABLE 1. RELATIONSHIPS OF S(8) GAIN AND THRESHOLD VALUES TO FRESNEL NUMBERS

1 菲涅耳数 F	2	5	10	20
2 增益距离积 G_{00}(cm/MW)	42.1	41.1	40.4	39.7
3 阈 值 P_c(MW/cm²)	1.27	1.24	1.22	1.20

Key: (1) Fresnel Number (2) Gain Distance Product
(3) Threshold Value

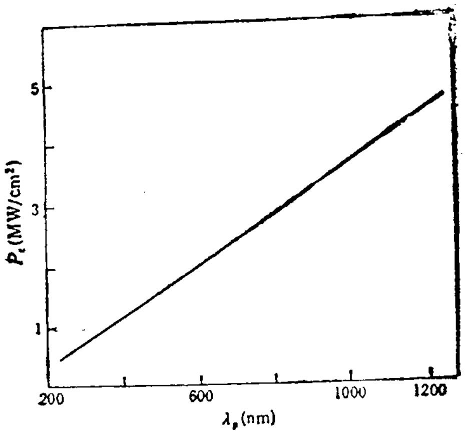

Fig.2 Relationships Between N_2 S(8) SRRS Threshold Value Strengths P_c and Incident Pump Wave Lengths λ_p.

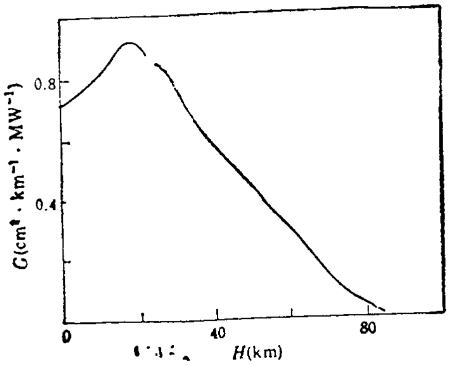

Fig.3 S(8) Gain G Relationships Following Changes in Height H

Besides this, as far as N_2 rotational Raman spectral lines are concerned, from widening coefficients as well as Boltzmann distributions related to concentration number reversal, in all cases, there are relationships to absolute temperature scales. Moreover, they will also influence gain coefficients. As a result, Raman gain coefficients will follow changes in T and vary [7]. The results are shown in Fig.4.

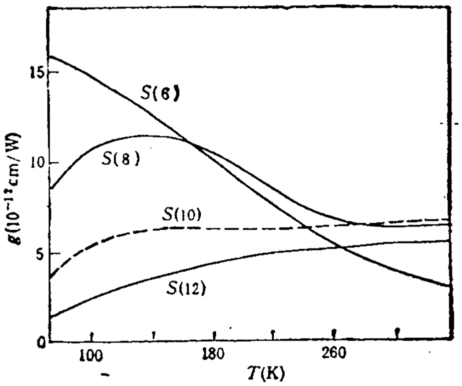

Fig.4 Relationships Between SRS Gain Coefficients g and Temperature T

The results discussed above were, in all cases, obtained under stable state conditions, that is, appropriate for use in situations where pump light is continuous laser or pulse laser light with pulse widths $t_p>>\tau_R$ (τ_R is Raman media relaxation time constant). However, when $t_p \sim \tau_R$, then, consideration should be given to instantaneous effects [8]. Detailed analysis clearly shows that threshold value powers follow reductions in t_p (pulse narrowing) and increase (see as shown in Fig.5). Moreover, this is exactly what we hoped. Besides this, when lasers go up, with regard to a certain pulse width t_p,t_p/τ_R follows increases in altitude above sea level and shows a decreasing tendency (see as shown in Fig.6). From this, it is possible to know that, in the upper atmosphere, instantaneous effects are even more obvious. As a result, influences on threshold values are also more evident. It is normally recognized that, when $t_p, t_p/\tau_R \leq 10$, it is then necessary to consider instantaneous effects. However, when $t_p, t_p/\tau_R \geq 20$, by contrast, it is possible to treat them as stable state situations in order to handle them. This is in line with the early Averbakh experimental results. They make use of pulse widths of 2.5ns ($t_p, t_p/\tau_R \sim 20$) and get threshold values in line with those given by stable state theory. However, when laser pulse widths of 1ns are used ($t_p, t_p/\tau_R \sim 8$), it is discovered that threshold values are clearly higher than steady state calculated values. The explanation for this is that, at this time, one should figure in instantaneous effects.

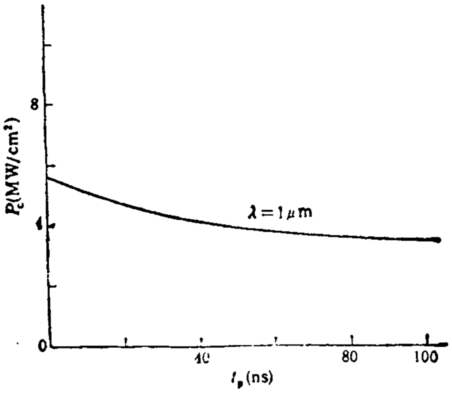

Fig.5 Threshold Value Strength P_c Relationships Following Changes in Pulse Width t_p

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Moreover M.A. Henesian and others [9] made use of Nova laser and experimental results clearly showed that threshold values when t_p = 1ns are approximately 30-40% higher than threshold values associated with t_p = 2.5ns.

Up to now, SRRS research on N_2 in the atmosphere has made some progress. A certain number of questions (for example, steady state SRRS questions) are already basically clear. However, in comparison to actual conditions, relevant theory was obtained by making multiple iterations of approximations. Corresponding experimental data was also scarce. As a result, there are still a good number of difficulties unresolved. For example, SRRS mechanisms when $t_p << \tau_R$ are still not clear. When beam quality is relatively bad (when degrees of spacial strength modulation are greater than 50%, or even higher), how does SRRS behavior change? LF-11 laser SRRS experiments done domestically first observed S(6) transition spectra. Does this mean that S(6) threshold values at this time are lowest? Due to the fact that LF-11 laser beam quality is very bad (spacial modulation 70%), as a result, one type of possible explanation is that beam quality has very great influences on N_2 SRRS in the atmosphere. However, at the present time, there is still no quantitative relationship. This awaits further theoretical analysis and experimental research.

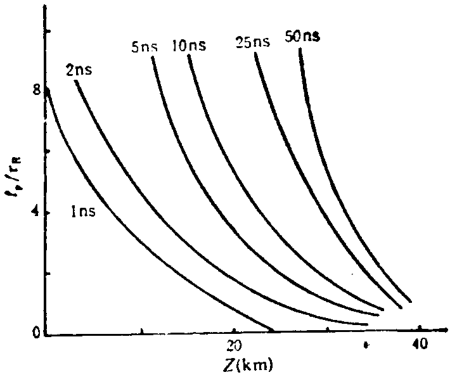

Fig.6 t_p/τ_R Relationships Following Changes in Altitudes Above Sea Level Z

Summarizing the above, it is possible to know that, if one wants to guarantee the quality of strong laser transmissions in the atmosphere--besides opting for the use of a number of compensating measures--raising the threshold values of nonlinear optical effects (for example, SRRS) is one type of effective method. With regard to SRRS, (1) select relatively long wave lengths, (2) select relatively short pulse widths, (3) take laser weapons and deploy them in upper layer space, (4) improve laser beam quality as well as enlarging emissive optical component dimensions, (5) employ series pulse strings, and so on, which possess appropriate intervals, to be able to guarantee strong laser quality during transmission.

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REFERENCES

[1] E. L. Woodbury et al., *Proc. IRE*, **50** (1962), 2347.
[2] Y. R. Shen et al., *Phys. Rev. A*, **137** (1965), 1787.
[3] N. Bloembergen, *Am. J. Phys.*, **35** (1967), 989.
[4] V. S. Averbakh et al., *Sov. J. Quant. Electron.*, **8**(1978), 472.
[5] M. Rokni et al., *IEEE J. Quant. Electron.*, **QE-22** (1986), 7, 1102.
[6] G. C. Herring et al., *Appl. Opt.*, **26**(1987), 15, 2988.
[7] G. C. Herring et al.. *Opt. Lett.*, **11** (1986), 6, 348.
[8] 胡志平等,电子科技大学学报, **18**(1989), 3, 267.
[9] M. A. Henesian et al., *Opt. Lett.*, **10**(1985), 11, 565.

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