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Solar-Pumped Solid State Nd Lasers

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ABSTRACT

Solid state neodymium lasers are considered as candidates for space-based solar-pumped laser for continuous power transmission. Laser performance for three different slab laser configurations has been computed to show the excellent power capability of such systems if heat problems can be solved. Ideas involving geometries and materials are offered as potential solutions to the heat problem.

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INTRODUCTION

Since the late 1970's, NASA has pursued a program to assess the technology required for and the practicality of space systems which, in essence, would collect solar power (the prime natural source in near-Earth space) at a central space station and transmit it through laser beam "power lines" to other space locations where it would be converted to thrust, electrical power, and/or other useful forms. A key element of such a system is, of course, the laser. Chemical, nuclear, and electrical power can be used to power lasers, but each of these requires one or more coupling mechanisms and adds to system complexity. The use of direct solar pumping obviates the inefficiencies associated with coupling mechanisms and reduces system complexity. Hence, solar-pumped lasers show promise as power transmitters in space.

Initially, research was directed toward gas and liquid lasants mainly because they had inherent cooling advantages. More recently, attention has turned to solid lasants. Several experiments (refs. 1, 2, 3) have produced lasing by irradiating solid materials directly with concentrated sunlight. Others (refs. 4, 5, 6) have produced lasing with pump sources whose characteristics could be easily matched by the Sun. However, these lasers have been "proof-of-principle" lasers that never attained the high power levels (multi-kilowatt) and/or continuous operation needed for practical space power transmission. Nevertheless, their potential for high output power exceeds that of gaseous and liquid lasers and, in the light of recent ideas, warrants further consideration.

Achieving practical power levels and durations in solids requires the solution of several problems, all of which are interrelated (e.g. heat dissipation, mechanical stress, and beam quality). Here we emphasize the problem of heat dissipation, although several problems are addressed to some degree.

Heat dissipation has historically been the most prominent problem associated with continuously operating solid state lasers. Put simply, solid state lasers depend upon heat conduction in the host material to dissipate heat, but conductive heat removal from the traditional geometries (rods, disks and slabs) compares most unfavorably with the cooling that can be obtained with the flow properties of liquid and gas lasants. Conventional solid state lasers simply cannot dissipate heat fast enough at high power levels to avoid physical damage. Currently, the highest power in true continuous operation available from a commercial solid state laser is 100 watts (ref. 7), but recent advances in technology promise to increase that number. Slab laser geometries (refs. 8, 9) already offer more power and better beam quality than rods and disks, but are still heat limited. The purpose of this report is to summarize recent in-house calculations, ideas, and investigations of materials and geometries that potentially can increase the power capabilities of solar-pumped Nd:glass lasers.

GEOMETRIES

A. Slab

"Slab" refers to a geometric shape the length and width of which are much greater than its thickness. At least four faces are right rectangles. Opposing faces are flat and parallel. This geometry offers the advantages of increased surface area for heat flow, larger mode volume for more power output and first order cancellation of output beam distortions (if the laser beam is totally internally reflected from side to side within the slab.)

Slab geometries have been used with a number of Nd-doped (Neodymium-doped) host materials including YAG (Yttrium Aluminum Garnet), glass, SOAP (Silicate OxyAPatite) and GGG Gadolinium Gallium Garnet) (ref. 8), but none were excited by real sunlight. To assess the general power capabilities of Nd:glass slabs, continuous output powers for various conditions have been calculated. Two methods were used.

The first method used a laser output power equation developed by Seigman (ref. 11), a slab thermal stress equation and a solar pump rate equation to predict laser output powers, solar concentrations, and Nd-doping densities at which slabs could operate without breaking.

The second method addressed laser output power only (thermal stress could be evaluated separately) and was a more detailed power calculation because it included first-order effects of:

a. Fluorescent line broadening due to slab heating.

b. Concentration quenching (decrease in upper laser level lifetime due to Nd-ion density)

c. More physical constants.

Figure 1 shows the four-level energy diagram appropriate for the Nd:Glass laser with pumping rates (P_1, P_2) and decay times (τ_{21}, τ_{20}, τ_{10}) required by the second method. Equations 1, 2 and 3 express the relationships of pumping rates, energy level populations (N_1, N_2), and photon number (n) of an "average" cavity mode.

$$\frac{dn}{dt} = K(N_2 - N_1)n + KN_2 - \frac{n}{\tau_c} \qquad (1)$$

$$\frac{dN_1}{dt} = K(N_2-N_1)n + \frac{N_2}{\tau_{21}} - \frac{N_1}{\tau_{10}} + P_1 \qquad (2)$$

$$\frac{dN_2}{dt} = -K(N_2-N_1)n - \frac{N_2}{\tau_{21}} - \frac{N_2}{\tau_{20}} + P_2 \qquad (3)$$

where,

K = cavity coupling coefficient

$$= \frac{\alpha_i}{8\pi V} \left(\frac{\lambda}{n_o}\right)^3 \frac{\lambda}{\Delta\lambda} \frac{1}{\tau_{21}}$$

α_i = polarization factor = 1

V = laser volume

λ = laser wavelength

$\Delta\lambda$ = bandwidth of atomic transition

n_o = index of refraction of glass host

τ_c = cavity lifetime (of a photon)

$$\tau_c = \frac{n_o L}{c[\ell n \frac{1}{r_1 r_2} + 2\,\alpha_o L]}$$

L = cavity length

c = speed of light

r_1 = amplitude reflectance of output mirror

r_2 = amplitude reflectance of rear mirror

α_o = cavity absorption and scattering losses

For steady-state conditions, the time derivatives equal zero and the three equations can be solved for N_1, N_2 and n. The solution for n reduces to equation (4) which can be solved for n by computer iteration.

$$\frac{n\,(P_1 + P_2\,) + P_2/K\tau_{10}}{\frac{1}{K\tau_{10}}\left(\frac{1}{\tau_{21}} + \frac{1}{\tau_{20}}\right) + n\left(\frac{1}{\tau_{20}} + \frac{1}{\tau_{10}}\right)} - \frac{nP_1}{n\left(\frac{1}{\tau_{10}} - \frac{1}{\tau_{21}}\right) + nK + \frac{1}{\tau_{10}}} \tag{4}$$

$$- \frac{n + \frac{1}{K\tau_{10}}}{K\tau_c + \frac{\tau_c}{n\tau_{10}} + \frac{\tau_c}{\tau_{10}} - \frac{\tau_c}{\tau_{21}}} = 0$$

The polarization factor, α_i, of cavity coupling coefficient, K, for the glass material is assumed to be unity as it is for all materials with randomly oriented atoms.

Both methods required as input data the solar pumping rate which was obtained from a separate computer program. The solar pumping rate is expressed by the integral:

$$\int_{325}^{899} S(\lambda)\left[\frac{(1-R)(1-e)}{1 - eR}\right] d\lambda$$

where

$S(\lambda)$ = solar spectral power distribution given by reference 12

R = reflectance normal to slab surface

e = $e^{-N\sigma(\lambda)\tau}$

N = neodymium ion density

$\sigma(\lambda)$ = ion spectral absorption cross section

τ = slab thickness

The ion spectral absorption cross section was approximated by Gaussians of various amplitudes, widths, and center wavelengths within the wavelength band of interest. Nd:glass absorption and the solar spectrum are shown in figure 2. The program computed the integral at two nanometer intervals as a function of the product , $n\tau$. (The bracketed term in the integral accounts for absorption of the main beam and multiple reflections between the slab surfaces.) All absorbed power appears in the laser as fluorescence, heat, or output power.

Calculations were made with both methods. However, the results of calculations made by the second method are presented here for reasons previously stated and are tabulated in tables I, II and III. Table I shows laser performance of a slab 18 cm long by 1 cm wide by 2 mm thick. (This is an arbitrary choice of size. Wider and longer slabs can produce more power.) Concentrated sunlight makes one pass through the thickness. Output power maximizes as neodymium doping density increases at a given solar concentration and that doping density at maximum power increases gradually with solar concentration (~2.8 percent at 4000 to ~3.8 percent at 10,000). Output reflectances are those values which maximize output power at a particular doping density.

Table II shows the performance of the same slab except it is twice as thick. Compared to the thinner slab, the thicker slab will operate at a higher average temperature and less output power at the same solar concentration and doping. This is attributed to a reduction in the cavity coupling coefficient caused by the increased volume and to a decreased ability of the slab to conduct heat away.

Table III shows the performance of the thin (2 mm thick) slab with two passes of concentrated sunlight. Two passes of concentrated sunlight represent a light trap in its simplest form and, in terms of power output, proves to be the best scheme of the three. (More efficient light traps are possible.)

The performances shown by the three tables are not the best possible performances that can be achieved by slab lasers (e.g. similar calculations for a solid Nd:glass (phosphate) slab show larger output powers), but are believed to be representative if parasitic oscillations, amplified spontaneous emission, and infrared absorption by the glass are insignificant. More importantly, the computer program provides a framework within which parameters may be adjusted so that computed performances can be made to match the actual performances of real slab lasers.

Table I

Lasing Performance of a 2 mm-Thick Nd:Glass (Silicate) Slab with a Single Pass of Concentrated Sunlight

Solar Concentration	Solar Power Input (Watts)	Wt. % Nd	Output Reflectance	Avg. Slab Temp. (°K)	Total Fluorescent Pwr. (Watts)	Max CW Output Pwr. (Watts)	Laser Efficiency (%)	Approx. Solar Colector Area (M^2)
2000	4871	1				no lasing		
		3				no lasing		
		5				no lasing		
		7				no lasing		
4000	9742	1	.94	325	267	29		14.4
		3	.94	333	334	42	.4	14.4
		5	.96	336	487	21		14.4
		7	-	-	-	no lasing		
6000	14612	1	.90	340	323	90		21.6
		3	.89	351	423	123	.8	21.6
		5	.92	360	601	94		21.6
		7	-	-	-	no lasing		
8000	19483	1	.86	353	382	166		28.8
		3	.86	369	480	224	1.1	28.8
		5	.89	382	692	196		28.8
		7	.97	381	1227	23		28.8
10000	24354	1	.84	367	414	253		36
		3	.83	387	541	338	1.38	36
		5	.87	405	758	316		36
		7	.96	412	1314	86		36

TABLE II

Lasing Performance of 4 mm Thick Nd:Glass (Silicate) Slab with a Single Pass of Concentrated Sunlight

Solar Concentration	Solar Power Input (Watts)	Wt. % Nd	Output Reflectance	Avg. Slab Temp. (°K)	Total Fluorescent Pws. (Watts)	Max CW Output Pwr (Watts)	Laser Efficiency (%)	Approx. Solar Collector Area (m^2)
2000	4871	1				no lasing		
		3				no lasing		
		5				no lasing		
		7				no lasing		
4000	9742	1	.98	348	408	1.25		14.4
		3	.98	378	548	11.9	.122	14.4
		5	-	-	-	no lasing		
		7	-	-	-	no lasing		
6000	14612	1	.96	384	493	32.4		21.6
		3	.94	427	695	73.1	.5	21.6
		5	.96	451	1022	41.8		21.6
		7	-	-	-	no lasing		
8000	19483	1	.93	417	583	85.3		28.8
		3	.91	476	817	165.0	.85	28.8
		5	.94	519	1165	131.1		28.8
		7	-	-	-	no lasing		
10000	24354	1	.91	451	648	153.5		36
		3	.89	525	909	277.4	1.14	36
		5	.92	582	1315	244.3		36
		7	-	-	-	no lasing		

Table III

Lasing Performance of a 2 mm-Thick Nd:Glass (Silicate) Slab with a Double Pass of Concentrated Sunlight

Solar Concentration	Solar Power Input (Watts)	Wt. % Nd	Output Reflectance	Avg. Slab Temp. (°K)	Total Fluorescent Pwr. (Watts)	Max CW Output Pwr (Watts)	Laser Efficiency (%)	Approx. Solar Collector Area (m^2)
2000	4871	1	-	-	-	no lasing		
		3	.97	319	283	5.7	.12	7.2
		5	-	-	-	no lasing		
		7	-	-	-	no lasing		
4000	9742	1	.93	330	281	46.2		14.4
		3	.91	345	387	90.8	.93	14.4
		5	.93	355	572	75.3		14.4
		7	-	-	-	no lasing		
6000	14612	1	.88	346	352	123.6		21.6
		3	.86	368	480	218.9	1.5	21.6
		5	.89	387	694	215.0		21.6
		7	.97	389	1231	37.0		21.6
8000	19483	1	.85	362	398	218.8		28.8
		3	.82	391	561	369.6		28.8
		5	.86	418	793	386.9	1.98	28.8
		7	.95	430	1395	134.3		28.8
10000	24354	1	.82	378	447	324.2		36
		3	.79	414	627	535.1		36
		5	.83	447	897	578.0	2.37	36
		7	.92	463	1638	259.1		36

The calculations above show the performance possibilities. But will the slab tolerate the heat load? Theoretical work (ref. 8) shows that the maximum surface stress of a slab is given by:

$$\sigma_S = \frac{\alpha E Q t^2}{12\ K(1-V)}\ ,\ \text{or}\ Q = \frac{q\sigma_S}{\tau^2}$$

where

α = linear thermal expansion coefficient

E = Young's modulus

Q = heat load (watts/volume)

τ = slab thickness

K = thermal conductivity

V = Poisson's ratio

Maximum surface stress is very sensitive to slab surface micro-imperfections (fissures, scratches, etc.), however, so σ_S subtends a range of values. Special chemical treatment and polishing of glass surfaces are known to increase the maximum allowable surface stress and thereby increase maximum available laser output power by as much as an order of magnitude. Hulme's experimental work (ref. 9) shows a "practical" limit on Q of 90 watts/cm^3 for a 2 millimeter-thick silicate glass slab. Thus, the slab above can be expected to tolerate approximately 325 watts of heat. Since the quantum efficiency of the Nd is about 50 percent, the laser output and fluorescence power approximately equal the heat power, so the laser of table I is heat limited to an output power of about 30 watts at a solar concentration of 4000 and doping density of 1 percent. The "light trapped" (double pass) version of the same laser could operate at ~40 watts output power at slightly less than 4000 solar constants and 1 percent doping. It too is heat limited to nonoptimum operation.

A 4 mm-thick silicate slab (the laser of table II) could tolerate about 22.5 watts/cm^3 (ref. 9) or about 81 watts. Such a thick laser requires at least 4000 solar constants to lase continuously. At or above this irradiation level, the slab would be damaged. Therefore, the 4 mm-thick solid slab is not a viable configuration for continuous laser emission.

Recall that a number of assumptions were made for the calculations above. Actual laser performance can be expected to vary somewhat. The calculations demonstrate that heat limits the output power of this solid Nd:glass (silicate) slab to less than 50 watts with reasonable values of solar concentration. Much larger output powers would be available if heat transfer from the laser could be improved, the area irradiated by the Sun increased, and/or the laser glass made stronger.

B. Beads

Heat transfer in glass lasers could be improved by increasing the cooling surface-to-volume ratio. In a solid slab this would be accomplished by making the slabs thinner, but there are limits to thinness imposed by the need for structural rigidity. An alternate method is to form a "pseudo-slab" of Nd-doped spherical beads. The basic idea is to immerse many small glass beads in a liquid that closely matches the index of refraction of the beads at the laser wavelength. This minimizes laser power loss due to scattered radiation. The heat from the beads will be transferred more efficiently to the liquid and the beads and/or liquid may be cycled through an external cooler just as gaseous and true liquid lasers can be cycled.

If a pseudo-slab is formed by one layer of beads that have diameters equal to the slab thickness, the surface-to-volume ratio is improved by a factor of 3. This makes possible a pseudo-slab of roughly the dimensions we have discussed with an output power greater than 300 watts. If there are N layers, on the average, within the slab thickness, then conductance approaches a value 3N times greater than a solid slab. In the limit of colloidal suspensions of particles $\sim 10^{-3}$ mm in diameter, pseudo-slabs could feasibly be scaled to sizes that could emit megawatts.

No physical principle has yet been found that requires the beads to be spherical in shape. Crushed glass particles (random shapes) may work also as long as the refractive indices of the particles and the liquid are well matched. (It is interesting to note that for particles immersed in an index matched fluid, the thermal conduction problem may solve itself! That is, large particles would continue to break into smaller particles as long as heat conductance is insufficient. As particles become smaller, heat conductivity would increase and limit the particle fracture rate.) Microphotographs of randomly shaped particles (ref. 10) suggest that they may be more difficult to wet with a liquid. This nonwetting might greatly affect light scattering which appears as a loss in the laser cavity. Otherwise, spherical particles are a convenience for the experimentalist and mathematician.

The appropriate fluid or fluid mixture has not yet been chosen, but several desirable properties can be identified:

a. Very small optical absorption and scattering, especially at the laser wavelength.

b. Index of refraction equal to the index of the laser host material at laser wavelength. (This may require a diluent.)

c. Large thermal conductivity and specific heat.

d. Very little molecular degradation due to heat and light intensity.

e. Good flow properties.

f. Low chemical reactivity.

g. Nonhazardous fire and health ratings.

h. Good wetting properties with laser host or compatibility with suitable surfactants.

i. Low cost and good availability.

j. Compatibility with Rhodamine, Coumarin, and other laser dyes.

C. Moving Slab

A variation of the bead/liquid combination would be to move a solid glass slab out of the solar pumping beam to limit the exposure (and heat) of any particular area element of the slab. That particular area element would then go through a relatively long cooling period and return to the pumping beam. (This is analogous to pumping beads and liquid in a cycle, but here the geometries available for cycling are limited by rigidity.) The heating/cooling cycle might appear as shown in figure 4. Normally, a slab fixed in position would assume a temperature at which the cooling rate equals the heating rate (steady state). For a small cycle rate, the average temperature would decrease somewhat. For a large rate, absorbed energy would be spread more uniformly over the entire slab, resulting in an even smaller slab temperature that approaches the value:

$$T = \left(\frac{dA}{A}\right) T_o$$

where

dA = area of slab element illuminated

A = area of slab

T_0 = steady state temperature of illuminated slab element

The moving slab concept may be implemented by a number of geometries. Among them are: (1) a spinning annular disk, (2) a rotating cylinder, and (3) various "Gatlin gun" concepts.

D. Fibers

Another viable scheme for handling the heat load of a pseudo-slab employs fibers. Extremely thin (typically 10 μ in diameter) fibers dissipate heat about two-thirds as well as beads of the same diameter and, in addition, can be made to propagate laser light in a single mode without external devices. (Single mode operation is desirable for transmission over very long distances.) Obtaining coherent output from a large number of fibers in parallel is a problem that requires examination. Sufficient interfiber crosstalk must be obtained to lock the phases of the fibers. The crosstalk may be obtained through the sides and/or the ends of the fibers.

Existing technology of fiber optics used for communication can be applied to the production of fiber lasers. In essence, this requires the addition of Nd^{3+} to the glass melt prior to fiber formation. Such fiberlasers have already been made (ref. 13), but, to our knowledge, a large number of them have not been operated in parallel.

Power per fiber (10 μ diameter) is limited by stimulated Raman and Brillouin scattering to about 0.75 watts (ref. 14), but this poses no problem to achieving megawatt output powers because practical slab thicknesses (millimeters) and widths required for appropriate solar coupling provide room for far more than the minimum required number of fibers. The use of fibers as laser elements also offers the possibility of radical geometry variations that may improve optical coupling with the Sun.

MATERIALS

Much work has been done on materials. A broad class of lasers (one of which is neodymium:glass) is formed by one of the rare-earth elements in various host materials such as glasses, crystals, and ceramics made of various elements (ref. 12). The mechanical and optical properties of these lasers are determined mainly by the host material since the lasant usually constitutes only a few percent of the lasing medium. A more recent development has been the addition of sensitizers to the lasing medium such as the addition of Cr to Nd:YAG. The sensitizer effectively increases the solar absorption by the lasing medium, potentially providing more laser output power. However, an analysis of the increased heating versus power output has not been found. This technique for increasing power output of solid state lasers should be evaluated both theoretically and experimentally.

An alternative method for increasing solar absorption might be to add an absorbing material such as a dye to the liquid coolant. The added material would fluoresce in the pump band of the lasant, but, very importantly, the heat generated would be outside the glass.

SUMMARY

Solid state lasers are well developed and understood both theoretically and experimentally but come from a tradition of cylindrical geometries that is not well suited to dissipate the large heat loads of the multi-kilowatt lasers necessary for space power transmission. Neither is there a wealth of experience with solar pumping as is proposed in such space-based lasers. The more recent solid slab geometry offers thermal and optical improvements, but is still inadequate.

Specified solid Nd:glass (silicate) slabs have been evaluated for output power and heat-induced stress. Calculations indicate that a slab 18 cm by 1 cm by 2 mm is capable of several hundred watts of continuous output power at reasonable solar concentration. New geometries have been proposed to alleviate the heat limitation: (1) suspension of glass particles in liquid, (2) moving slabs, and (3) fiber lasers. Other lasing dopants, other host materials, sensitizers, fluorescent dyes, size enlargement and more efficient solar "light traps" (more than two passes) can be used with the new geometries to achieve practical power levels for space transmission. The computer programs developed for the analysis presented here provide a framework for use with new lasers.

REFERENCES

1. C. G. Young: A Sun-Pumped CW One-Watt Laser, Applied Optics, vol. 5, no. 6, June 1966, pp. 993-997.

2. Schneider, R. T.; Kurzweg, U. H.; Cox, J. D.; and Weinstein, N. H.: Research on Solar-Pumped Liquid Lasers, NASA CR-172121, March 1983.

3. Abrashi, H.; et al.: A Solar-Pumped CW 18W Nd:YAG Laser, Jap. J. Applied Optics, 23, 1984, pp. 1051-1053.

4. Beck, R. and Gurs, K.: Ho Laser with 50-W Output and 6.5 Percent Slope Efficiency, Journal of Applied Optics, 46, no. 12, Dec. 1975.

5. Chernoch, J. P.; and Martin, W. S.: Performance Characteristics of a Face Pumped, Face Cooled Laser, the "Mini-FPL," Technical Report AFAL-TR-71-3, Wright-Patterson AFB, March 1971.

6. Reed, M.; et al.: Static Gas Conduction Cooled Slab Geometry Nd:Glass Laser, IEEE J. of Quant. Elec. vol. QE-21, 5, May 1985.

7. 1985 Laser Focus/Electro Optics Buyer's Guide.

8. Eggleston, J. M.; et al.: The Slab Geometry Laser - Part I: Theory, IEEE J. of Quant. Elec. vol. QE-20, no. 3, March 1984.

9. Hulme, G. J.; and Jones, W. B.: Total Internal Reflection Face Pumped Laser: Concept and Design Consideration, SPIE vol. 69 Laser Systems, 1975.

10. Schuerman, D. W., ed.: Light Scattering by Irregular Shaped Particles. Plenum Press, 1980.

11. Seigman, A. E.: An Introduction to Lasers and Masers, McGraw Hill, Inc., 1971.

12. Koechner, W.: Solid-State Laser Engineering, Springer-Verlag, 1976.

13. C. A. Young: Continuous Glass Laser, Appl. Phys. Lett., vol. 2, no. 8, pp. 151-152, 1963.

14. Levi, L.: Applied Optics, vol. 2, John Wiley and Sons, 1980.

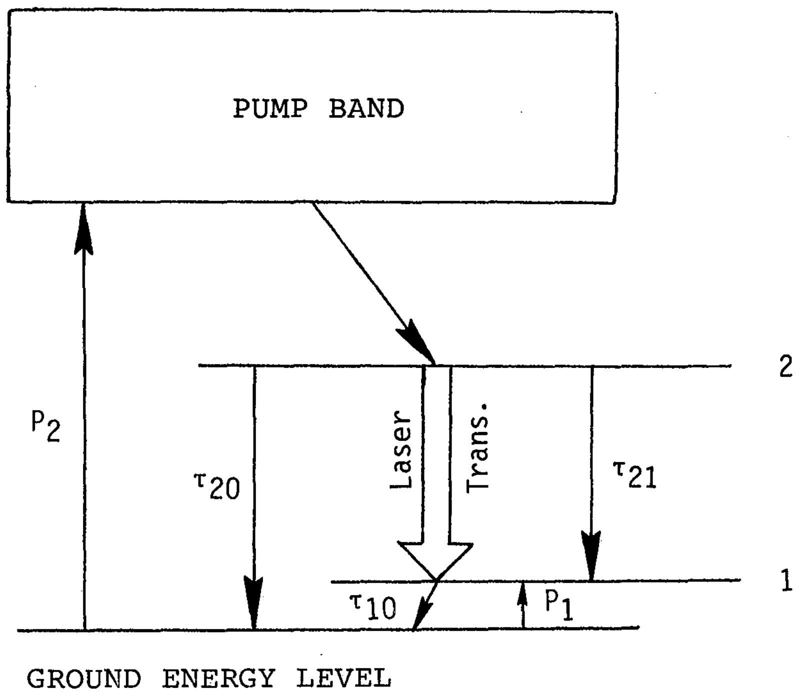

Fig. 1.- Simplified Energy Level Diagram for Nd^{3+} Laser

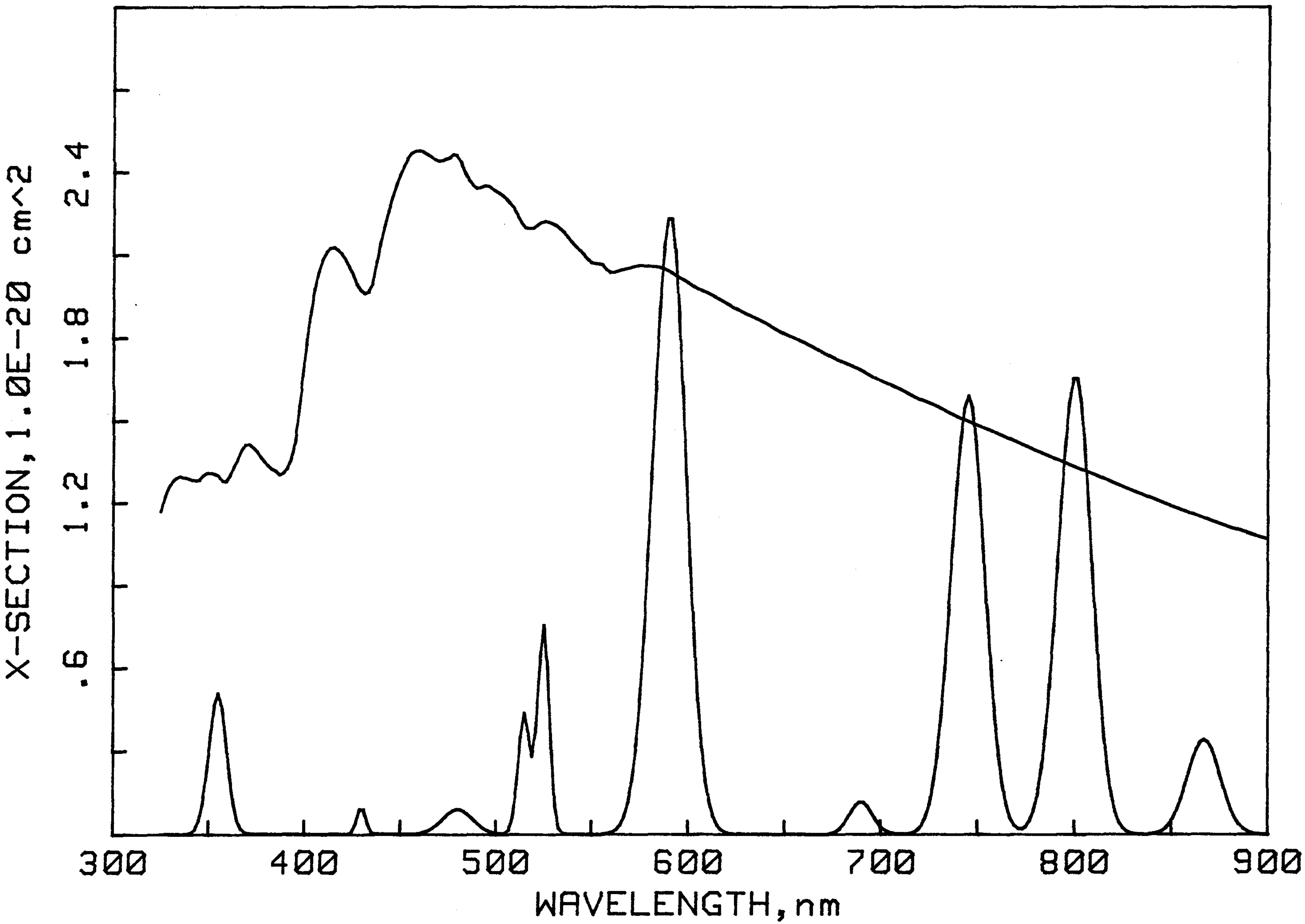

FIG. 2 - Nd ABSORPTION SPECTRUM

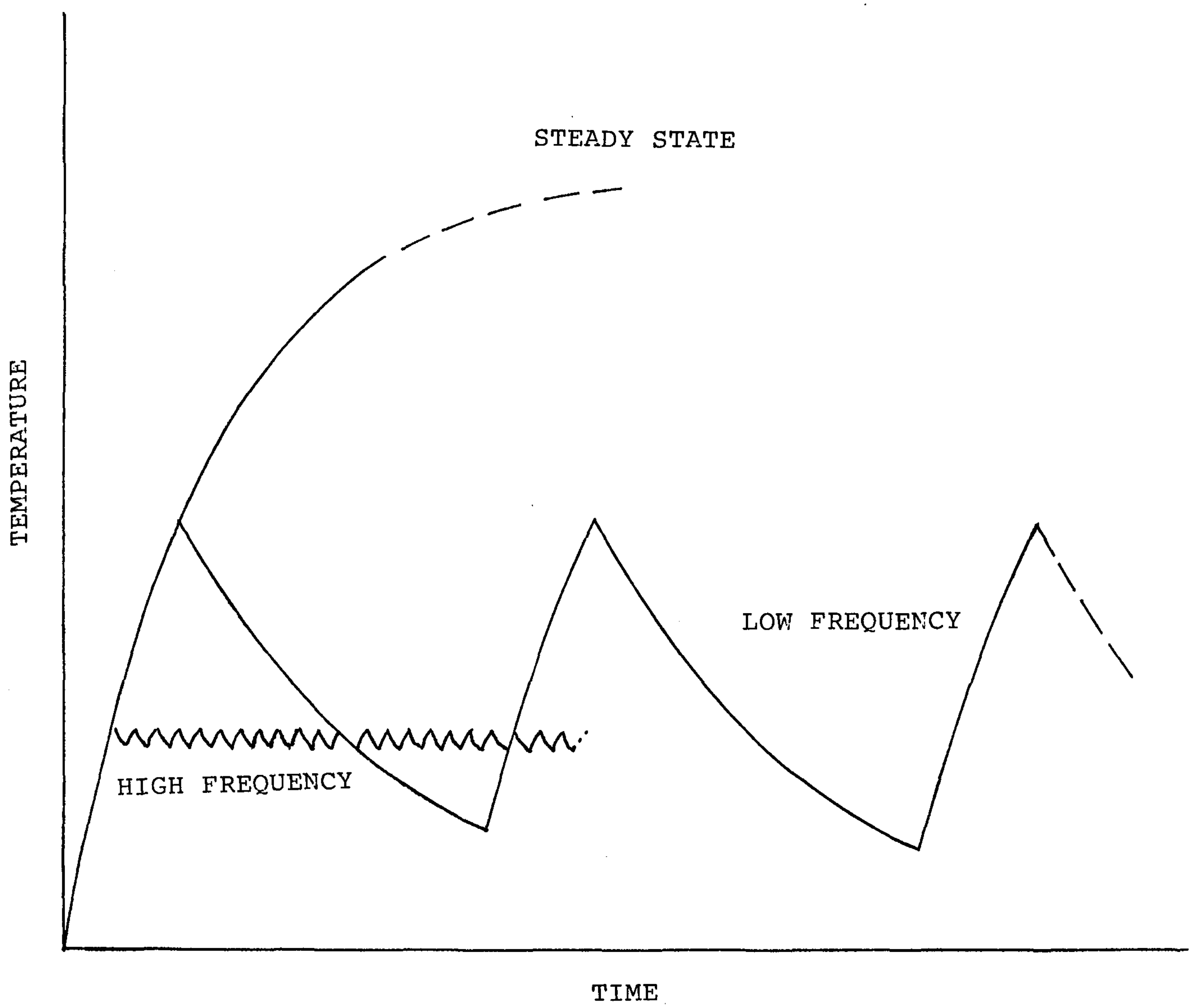

FIG. 3.- TEMPERATURE VARIATION IN A ROTATING SLAB LASER

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16. Abstract

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