

UNCLASSIFIED

AD NUMBER

AD428678

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

**Distribution authorized to U.S. Gov't. agencies and their contractors;
Administrative/Operational Use; 01 DEC 1963.
Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.**

AUTHORITY

ONR ltr dtd 15 Jun 1977

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

UNCLASSIFIED

AD 428678

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

AD No.

DOC FILE

Covering Period: June 1, 1958 - December 31, 1963

428678



DIVISION OF ENGINEERING AND APPLIED PHYSICS
HARVARD UNIVERSITY - CAMBRIDGE, MASSACHUSETTS

NO OTS

⑤ 234300

Office of Naval Research

Contract Nonr-1866(49)

NR - 015 - 807

ARPA Order No. 455

⑨

SEMI-ANNUAL TECHNICAL SUMMARY REPORT.

1 Jan - 1 Dec 63,

Covering Period June 1, 1963 - December 1, 1963

⑥ PROJECT DEFENDER.

The research reported in this document was made possible through support extended the Division of Engineering and Applied Physics, Harvard University, by Project DEFENDER under the joint sponsorship of the Advanced Research Projects Agency, the Office of Naval Research, and the Department of Defense. Reproduction in whole or in part is permitted for any purpose of the United States Government.

~~Submitted by:~~

⑩ by

N. Bloembergen, ~~Project Director~~

Cruft Laboratory

Division of Engineering and Applied Physics

Harvard University

Cambridge, Massachusetts

REC'D
FEB 6 1964
TISIA A

SEMI-ANNUAL TECHNICAL SUMMARY REPORT
Covering Period June 1, 1963 - December 1, 1963

Personnel

Prof. N. Bloembergen

Dr. J. Ducuing

Mr. R. Chang

Mr. P. Lallemant

Mr. L. Malmstrom

Project Director

Research Fellow

Graduate Student

Graduate Student

Graduate Student

SEMI-ANNUAL TECHNICAL SUMMARY REPORT

Covering Period June 1, 1963 - December 1, 1963

Synopsis

The nonlinear optical constants of several III-IV semiconductor compounds have been determined by reflecting methods developed in the Gordon McKay Laboratory at Harvard University.

A study of fluctuations in the second harmonic production of light has been completed. A detailed technical report will be issued.

A small rotating prism ruby laser has been built. The peak output power in Q-switched operation is 4 megawatt or 16 megawatt/cm^2 in the unfocused beam. A large ruby laser amplifier rod with minimum gain of 15 dB has been purchased from Maser Optics Inc., and will be delivered shortly. The resulting high power giant pulse laser will be used for study of Raman effects and four photon scattering of light.

The theory of complex nonlinear susceptibilities is being extended and applied to situations involving Raman-type nonlinearities.

A. Nonlinear optical constants of III - IV compounds

The second harmonic production by a ruby laser beam infringing on single crystal mirrors of Ga As, Ga Sb, In As and In Sb has been observed in reflection. The experimental technique of reflected harmonic beams has been described by Ducuing and Bloembergen^{1, 2} and was developed under parallel contracts at Harvard University.

The method gives a more reliable value for the nonlinearity than the second harmonic production in semiconductor lasers, because the geometry is better defined. Furthermore, the frequency and materials can be changed independently. The following values for the nonlinear constants have been obtained for ω corresponding to the 6940 Å ⁰ ruby line.

	Ga As	Ga Sb	In As	In Sb
$\chi_{14}(2\omega = \omega + \omega)$ in e. s. u.	9×10^{-7}	6×10^{-7}	6×10^{-7}	1.5×10^{-6}

The nonlinearity is about 250 times larger than in KDP. This is due to resonance, since both the fundamental and the second harmonic frequency are absorbed in these materials. The second harmonic production is not very large in spite of the large nonlinearity, because only the second harmonic polarization in a small surface layer corresponding to the absorption depth at 2ω is effective in the harmonic generation.

Some samples of gallium arsenide phosphide alloys were also investigated. In the sample with the highest P-concentration, the ruby fundamental frequency was below the absorption edge. No significant change in the nonlinearity was found. The nonlinearity will also be measured in all samples at the fundamental wavelength of 1.06 microns of a neodymium glass laser.

A theoretical investigation of the nonlinearity, utilizing the known band structure of the III - V compounds, is in progress. The theory can explain why there is no drastic dispersion in the nonlinearity as the fundamental frequency crosses the absorption edge.

B. Fluctuations in second harmonic production

An experimental investigation has been made of stochastic effects in second harmonic production by ruby laser beams in quartz and KDP platelets. Since several modes are simultaneously oscillating in each spike of the ruby laser, and since the amplitudes and relative phases of these modes are random functions, the generated second harmonic intensity is not a unique function of the primary intensity. This is strikingly confirmed by an experiment in which a ruby laser beam is split into two beams of equal intensity. Each beam creates a second harmonic. The intensity ratio of the two second harmonic beams is constant. Variations in this ratio can, however, be induced, if the mode pattern in one of the fundamental beams is mixed up with respect to the other. This can be achieved by an odd number of reflections or by a non-absorbing frosted glass diffuser. A complete description of theory and experiment will appear as a technical report and also as a paper accepted for publication in the Physical Review.³

C. Raman effects

A preliminary theoretical study has been made of the Stokes and anti-Stokes spectra induced by a laser beam in a fluid. It has been shown that these Raman effects are described by the imaginary part of a fourth rank susceptibility tensor, whose real part describes the parametric interaction between four light waves. The quantum theoretical calculation

of Bloembergen and Shen⁴ has been extended to describe the nonlinear susceptibilities near a molecular resonance. Terhune,⁵ Stoicheff⁶, and others⁷ have reported several interesting observations, which may at least in part be explained by interference between the Raman effects and the parametric generation of waves, as well as by scattering interactions between the incident laser and the Stokes and anti-Stokes light beams. All these effects are described by nonlinear susceptibility tensors of the same order.

These theoretical studies indicate the need for experiments with better controlled geometry than is obtainable in present experimental arrangements, which use a focused laser beam and generate Stokes radiation in all directions. It is planned to perform experiments on the interaction between laser beams and beams displaced by a molecular resonance frequency in well defined directions. Such beams may be generated by a Raman laser. They can be separated and brought together by selective mirror systems at variable angles in a fluid sample of the same constitution as the Raman laser. A small ruby laser, Q-switched by a rotating mirrors, has been constructed. It was successfully tested to give an output of 0.16 Joules during a 40×10^{-9} sec pulse. This corresponds to a peak power in the unfocused beam of 16 megawatts/cm². This beam will be amplified by at least 15 dB by a ruby laser amplifier. A Maser Optics model 3020 ruby laser has been

ordered for this purpose. This equipment will be used in the experimental investigation of Raman-type nonlinearities.

References

1. J. Ducuing and N. Bloembergen, Phys. Rev. Letters 10, 474 (1963).
2. N. Bloembergen and J. Ducuing, Physics Letters 6, 5 (1963).
3. J. Ducuing and N. Bloembergen, Phys. Rev. (to be published).
4. N. Bloembergen and Y. Shen, Phys. Rev. 133 (to be published).
5. R. W. Terhune, Bull. Am. Phys. Soc. 8, 359 (1963).
6. B. Stoicheff, Physics Letters 7, 186 (1963).
7. H. J. Zeiger, P. E. Tannenwald, S. Kern, and R. Herendeen, Phys. Rev. Letters 11, 419 (1963).

UNCLASSIFIED

UNCLASSIFIED