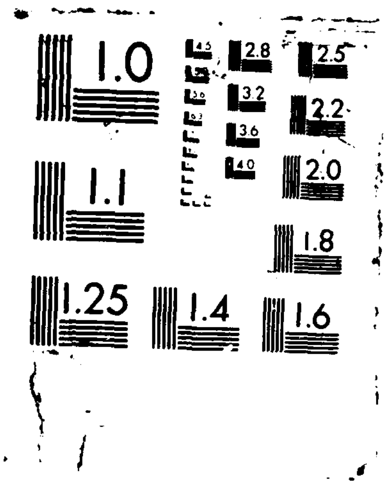
AD-A190 040 THEORY OF INTERACTIONS OF INTENSE LIGHT WITH NONLINEAR INHOMOGENEOUS AND..(U) PURDUE RESEARCH FOUNDATION LAFAYETTE IN A E KAPLAN OCT 87 AFOSR-TR-88-0162 1/1

UNCLASSIFIED AFOSR-85-0006 F/G 20/6 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

DTIC FILE COPY

(2)

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

AD-A190 040

DTIC ELECTE FEB 2 9 1988 D

1b. RESTRICTIVE MARKINGS

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release, distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
CD

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AFOSR-TR- 88-0162

6a. NAME OF PERFORMING ORGANIZATION
Purdue Research Foundation

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
AFOSR /NE

6c. ADDRESS *(City, State, and ZIP Code)*
West Lafayette, Indiana 47907

7b. ADDRESS *(City, State, and ZIP Code)*
Bldg 410
Bolling AFB, DC 20332-6448

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
SAME AS 7a

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
AFOSR-85-0006

8c. ADDRESS *(City, State, and ZIP Code)*
SAME AS 7B

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
61102F	2305/B2		

11. TITLE *(Include Security Classification)* Theory of Interactions of Intense Light with Nonlinear, Inhomogeneous, and Periodica Structrues and its Applications to Optical

12. PERSONAL AUTHOR(S)
Professor Kaplan

13a. TYPE OF REPORT
Final Report

13b. TIME COVERED
FROM 01/11/84 TO 31 Aug

14. DATE OF REPORT *(Year, Month, Day)*
87

15. PAGE COUNT

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

During the grant period, a number of new theoretical results were obtained ~~by this principal investigator~~ in the field of nonlinear optics and quantum electornics. This principal investigator has continued ~~to make~~ progress in the search of novel principles and effects in the field of uperfast optical switching, optical bistability, new sources of X-ray radiation, optic gyroscopes, general nonlinear optics, as well as in the development of a new fundamental field of quantum and nonlinear optics of single particles/

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
SCHLOSSBERG

22b. TELEPHONE *(Include Area Code)*
(202) 767-4908

22c. OFFICE SYMBOL
NE

AFOSR-TR- 88-0162

Final Technical Report

Grant AFOSR 85-0006

Theory of Interactions of Intense Light with Nonlinear, Inhomogeneous, and Periodic Structures and its Applications to Optical Bistability, Optic Gyroscopes, Nonlinear Spectroscopy, Radiation Protection, X-ray Emission, and Related Fields

School of Electrical Engineering
Purdue University, West Lafayette, IN 47907

Submitted to

the U.S. Air Force Office of Scientific Research
Program Manager - Dr. Howard Schlossberg

West Lafayette, Indiana
October 1987

Project Period: 2 years (November 1, 1984 - October 31, 1986)
with an additional no-cost extension (November 1, 1986 - August 30, 1987).

Principal Investigator:

Professor Alexander E. Kaplan
(301) 338-7018
October 1987

88 2 25 061

During the grant period, a number of new theoretical results were obtained by this principal investigator in the field of nonlinear optics and quantum electronics. This principal investigator has continued to make progress in the search of novel principles and effects in the field of superfast optical switching, optical bistability, new sources of X-ray radiation, optic gyroscopes, general nonlinear optics, as well as in the development of a new fundamental field of quantum and nonlinear optics of single particles.

These results were published in 46 papers (see list attached), among them 16 regular journal papers, 5 conference proceedings, and 25 conference papers. Four more articles were submitted for publication. Some of this research was done in collaboration with the researchers at Max-Planck-Institute for Quantenoptic (Germany), Optical Sciences Center at Arizona University, Simon Fraser University (Canada), and at Purdue.

The research progressed basically in these directions:

(i) X-rays and extreme UV emission excited by electron beams in solid-state superlattices

(ii) Light-induced enhancement of optic gyroscopes; multistabilities and installabilities in four-wave mixing

(iii) Nonlinear optics of a single slightly-relativistic electron.

(iv) Bistable solitons and their applications in nonlinear optics.

(v) Self-bending of laser beams

(vi) Other research

All of these research directions are briefly discussed below. Other events and activities relevant to this research are described in section

(vii) Other activities

(i) X-rays and extreme UV emission excited by electron beams in solid-state superlattices

Earlier [see also (1), (15), and (23)] in the research under AFOSR support, this principal investigator in collaboration with Dr. S. Datta demonstrated theoretically the feasibility to attain X-ray radiation at the wavelengths Å -200Å using intense electron beams (with energies 100 KeV - 1 MeV) passing through solid-state superlattices with short spatial periods (≈30–100Å). The proposed method is based on the so called resonant transition radiation; the main idea is to use a very short spatial period of material instead of using extremely high energies of the electron beam (e.g., such as ≈50GeV, as proposed by other researchers) that require use of large machines. Electron beams with such energies can be readily obtained in an university laboratory; the cost of the required equipment is insignificant compared with the cost of large ultrarelativistic accelerators currently used to obtain X-ray radiation by electron beams. The proposed method can provide a bright source of noncoherent radiation, and under special conditions, stimulated emission which may result in the development of X-ray and extreme-ulraviolet lasers.

In this research, this principal investigator in collaboration with Dr. S. Datta for the first time, to the best of his knowledge, developed a quantum (2) theory of resonant transition radiation, particularly, in superlattices. Recently, in collaboration with his student, C. T. Law, he developed a detailed theory (3, 20, 31, 36) of this radiation which takes into consideration two main damping processes in the system: scattering and absorption of electrons by the matter, and absorption of radiated X-ray photons. They showed that these factors result only in moderate increase of required energy of electron beam compared with the ideal nonabsorbing case. The most optimal energies of electron beam lie in the range 0.5 Mev-3Mev. These are still energies which could be attained using a standard equipment like Van de Graaff generators. Such energies are also readily available in research laboratories like Physics International Company which has the Pulserad 1150 with mean electron energy of 4.5 MeV and maximum beam current $\sim$ 100 KA. Higher beam current and electron energy can be found in the "Aurora" system of Harry Diamond Laboratories. Using these energies, the total thickness of the multilayer structure may be much larger which results in the substantial enhancement of X-ray resonant radiation. It was also found that because of the photon absorption, the increase of the electron energy above some "ceiling" level (which typically is as low as 2 - 10 MeV) is meaningless since it does not produce any further increase of the X-ray radiation.

In the most recent research (39, 50), the theory of the stong resonant transition radiation due to large anomalous dispersion of x-ray refractive index pertinent to the photo-ionization of the inner-shell atomic electrons was developed. It was discovered that a combination of materials with high and low atomic numbers can produce an intense X-ray radiation with very narrow peaks at the vicinity of K, L, ... absorption edges of each of the materials. The best "light" candidate materials to form "spacer" layers are berilium, bor, and carbon. The "heavy" solid-state materials to form "radiator" layers can be chosen from the entire periodic table; most of them were studied by us in order to find the maximum possible set of resonant lines. It was shown that energy of electron beam E_0 from 100 - 200 KeV to a few MeV is sufficient to give rise to the narrow width transition radiation (with a relative linewidth $\sim 10^{-4}$-10^{-5}) with wavelengths from 2 Å to 200 Å in a multilayer structure with a short spatial period (50 Å to 500 Å). A procedure was developed which allows one to choose appropriate materials (both for radiator and spacer) in order to obtain radiation with narrow resonant peaks at desired frequencies. A numerical procedure was also developed to optimize parameters of the periodic structure required to obtain maximum radiation. In this procedure, the spatial period, optimal total length, and resonant angle are evaluated. This completely specifies the design of the system. This system was further compared to other systems employing higher electron energy (100 MeV - 50 GeV) from the radiation efficiency point of view; it was shown that the proposed system (low electron beam energy plus short-period structure) is clearly preferable as an inexpensive narrow bandwidth X-ray source.

(ii) Light-induced enhancement of optic gyroscopes; multistabilities and instabilities in four-wave mixing

It was earlier proposed in this investigator's research supported by AFOSR that the fundamentally novel effect - light-induced nonreciprocity -- can arise due to interaction of sufficiently strong counter-propagating light beams in a nonlinear medium. It was shown that this effect can result in a large enhancement of the Sagnac effect and therefore - to enhancement of laser gyroscopes.

In this research, in collaboration with E. M. Wright, P. Meystre, and W. J. Firth, this investigator extended (8) this idea to the fiber-optic gyroscopes based on the light-induced nonreciprocity. Peculiarities of the nonlinear non-reciprocity in different nonlinear materials (liquids, gases, and semiconductors) were studied and potentials of nonlinear nonreciprocal spectroscopy as well as optical gyroscopes applications were explored.

In regard to these applications, it also became important to explore stability of the system, as well as possible range of instability and multistability. In four-wave mixing, in general, and particularly in degenerated collinear four-wave mixing (when the interacting counter-propagating waves have the same frequency) the issue of instability and feasible multistability become of considerable importance. This is because the nonlinear interaction of two strong waves takes place in such devices like lasers, laser gyroscopes (27), optically bistable resonators, etc.

In this research, this principal investigator in collaboration with his student, C. T. Law found (3), (19), (25), (33), (34) that two strong waves with almost arbitrary polarizations counter-propagating in a Kerr-like nonlinear material may exhibit a broad variety of multi-stable "input-output" characteristics. Particularly, they found an existence of multiple isolated branches (the so called "isolas") in these characteristics which suggest a formation of some "hidden" resonances in four-wave mixing. They also found an interesting process of "polarization dragging" (22) when one of the beam forces another one to change its polarization. It is planned to continue this research with the emphasis on stability and feasible instability of new regimes, as well as oscillations and chaotic motion resulting from the instability.

(iii) Nonlinear optics of a single slightly-relativistic electron

It was recently demonstrated by this principal investigator in the AFOSR-supported research [Phys. Rev. Lett. *48*, 138 (1982)] that even a very weak relativistic mass effect of a free electron can result in large nonlinear effects such as hysteresis and bistability in free-electron resonance. The proposed effect suggests, for the first time, bistable interaction of an electromagnetic wave with the simplest microscopic physical object. Most recently, consistent with this prediction, the hysteresis cyclotron resonances of a single electron was experimentally observed by G. Gabrielse et al. [Phys. Rev. Lett. *54*, 537 (1985)]. "Physics Today" (May 1985, p. 17) credited both the experimental observation and the theoretical prediction as very important discoveries. London-based journal "Nature" published an invited paper (7) on the subject by this principal investigator.

It has also been shown earlier by this principal investigator that the bistable cyclotron resonance can be expected also in solid state materials in which the effective mass, m*, of the electron strongly depends on the energy of its excitation (e.g., in InSb). This effect, being to some extent analogous to the relativistic mass-effect, can result in bistability if the nonlinear shift of the cyclotron frequency is larger than the frequency width of the resonant line.

In this research, the unified theory of both of these effects (i.e., hysteretic resonances based either on relativistic nonlinearity or on nonparabolicity of semiconductor quantum well) is developed in Ref (5) in which they are perceived as the ultimate examples of optical bistability. We are planning to extensively study these effects with the emphasis on kinetic and quantum theory of the bistable excitation of free electrons in vacuum and conduction electrons in semiconductors.

The most recent and exciting finding is the feasibility of multi-photon (9), (27), (35) optical excitation of a relativistic cyclotron resonance. A cyclotron resonance of a single electron (with the frequency Ω) may be excited by two laser beams (with their frequencies ω_1 and ω_2 being in infrared or visible range) when either $\omega_1 - \omega_2 = \Omega$ (three-photon process) or $\omega_1 - \omega_2 = 2\Omega$ (four-photon process). One can perceive this phenomenon as a starting point for an entirely new fundamental field which may be described as a ***nonlinear optics of a single electron*** (and single particles - in general). This principal investigator, in collaboration with his student, Y. Ding, found that the analogous effect exists for the conduction electrons in semicondutors (37). This effect in semiconductors may result in tunable excitation of radiation in far-infrared range and may find feasible application for infrared laser with a frequency tunable in a broad range. Most recently, a theory of three-photon excitation (44) for a high-level laser pumping was developed which revealed an amazingly complicated structure of this excitation with multiple isolated branches ("isolas"). The existance of higher-order processes of this kind was also predicted, which was described as higher-order cyclo-

Raman effect whereby $\omega_1 - \omega_2 = n\Omega$, where n is an arbitrary integer.

Most recently yet another high-order multiphoton effect with cyclotron electrons was found which consits in generation of subharmonics of laser frequency. It was demonstrated (38), (14), that homogeneous laser radiation in the visible or infrared ranges can excite high order subharmonics at the cyclotron frequency of free electrons in the millimeter or microwave ranges. This may provide coherent links between lasers and rf or mw atomic frequency standards. In order to divide frequency of CO_2 laser ($\lambda \approx 10\mu m$) by a factor 100 down to $\lambda \approx 1$ mm in one step, the cw laser power as low as 10^{-6} W is sufficient. Recently, this principal investigator was invited to present overview of his results on nonlinear optics of single electrons in an invited paper at IQEC'87 in May'87 (43). He was also invited to be a guest editor for a special issue of IEEE J. of Quantum Electronics on "Quantum and Nonlinear Optics of Single Electrons, Atoms and Ions".

(iv) Bistable solitons and their applications in nonlinear optics.

Very recently, in this research, [Refs (4,6,24)] a new property of soliton solutions of highly-nonlinear Schrödinger equation was discovered. Namely, it was demonstrated that a generalized nonlinear Schrodinger equation with certain nonlinearities allows for an existence of multistable singular solitons (i.e., singular solitons with the same carried power but different propagaton parameters). In nonlinear optics, these solitons may exist in the form of either short bistable pulses, or bistable self-trapping (both two- and three-dimensional). The class of nonlinearities was found which result in bistable solitons; explicite solutions were also found for some of these nonlinearities.

The soliton bistability may result in such effects as bistable (or multistable, in general) self-trapping of light in media with nonlinear refractive index, as well as bistable propagation of short soliton pulses in nonlinear optical fibers, since both of them may be described by the same nonlinear equation. Both of these effects may be viewed as an ultimate manifestation of multistable wave propagation since they are based on the simplest possible propagation configuration. They may also provide new opportunities in the field of optical bistability. Indeed, for example, a bistable self-trapping of light provides a potential for an optical bistable device entirely free from any cavity or Fabry-Perot resonators, single nonlinear interfaces or nonlinear waveguides formed by the nonlinear interfaces, retroflection self-action effects, four-wave mixing, etc. On the other hand, since the propagation of singular pulses in a homogeneous nonlinear medium and in nonlinear fiber waveguides is also governed by a nonlinear Schrödinger equation, these soliton pulses in the system with an appropriate nonlinearity may provide the first (to the best of our knowledge) known opportunity to attain a temporal (or dynamic) bistability as opposed to all known kinds of optical bistability which have been so far formulated in terms of steady-state regimes.

In the first publications (4,6,24), only steady-state solutions were obtained. It was very important to determine which of these solutions are stable and which are not. The analitic theory of nonlinear Schrödinger equations with arbitary nonlinearity does not exist yet; although the first step to the development of the theory of stability of new solutions was done by this principal investigator in (4), the (very nontrivial) criterium of their stability was actually conjuctured by him in (4,6). Surprisingly, this criterium was almost immediately verified in a computer simulation of collision between varios kind of new solitons done by Canadian researchers Enns and Rangnekar from Simon Fraser University [Phys. Rev. Lett. 57, 778 (1986), see also response (11)]. In his collaborative research with Enns and Rangnekar, immediatelly following those publications, this principal investigator discovered a competely new aspects in the theory of soliton stability (12), (41), (42), (48). It was found that for some highly-nonlinear Schrödinger equations (as contrary to a well-known cubic equation) the stabilities of solitary waves against small and large perturbations do not coincide which results in the existence of "weak" and "robust" solitons respectively. It was also shown that bistable solitons predicted earlier in the work (4, 6) are "robust" for some particular nonlinearities and, therefore, physically feasible. A general criterion for "robustness" of solitons for arbitrary nonlinearity has also been suggested.

(v) Self-bending of laser beams

In the previous research by this principal investigator, it was predicted that due to self-action of the light beam with asymmetric intensity distribution in medium with nonlinear refractive index, the beam may undergo self-deflection (or self-bending).

In this research, this principal investigator started an extensive activity, both theoretical and experimental, aimed to study this effect and explore its potentials for such device applications as a method of very fast angular scanning, and radiation protection of optical sensors. Recently, this research group has completed computer simulation of self-bending effect in thin nonlinear layers. Most recently, in the experimental research completed by G. Swartzlander under the supervision of this principal investigator, the angular self-deflection much larger than diffractional spreading has been observed in the experiment using a dye laser pumped by a 15-watt cw argon laser as a source and atomic sodium as a nonlinear medium. A paper with these results will soon be completed and submitted for publication.

(vi) Other research

This principal investigator continues to make progress in his quest for new effects in optical bistability; most recently he proposed a novel kind of optical bistability which is based on phase memory of optical nonlinear system rather than on bistability of its amplitude, Ref (18), (28). He also continues his effort in the field of nonlinear interfaces, Ref (26), (47), in which his research was recognized as a pioneering by a worldwide research community. He also explored general properties of resonant nonlinearities (13, 32, 47) and was involved in collaborative research (10), (29) with Dr. B. Gunshor and Dr. S. Datta group on nonlinear optics of new semiconductor superlattices.

(vii) Other activities

This principal investigator was involved in various activities related to his research supported by AFOSR, such as research community activity, supervising research of graduate student, presenting results of his research at other universities, etc. This Section also reflects on the recognition of his research by the research community in the field and the degree to what his results are used by other researchers.

Within last two years, this principal investigator supervised research of five graduate students; four of them were supported with his grants. Four of them received their M.S. degrees and continue to work toward their Ph.D. degree under his supervision (one of them, C.T. Law, is expected to graduate in the end of this year).

Within the same period of time, this principal investigator was a member of Organization and Program Committees at a few meetings and conferences on quantum and nonlinear optics as well as invited speaker and panel member in particular, at the workshop on Nonlinear Optics Material, held in Annapolis in May'86 (13),(32). In this period he did also more than 60 reviewer reports for the leading technical journals in the field, such as Phys. Rev. Lett., Optics Letters, Appl. Phys. Letters, Phys. Lett., Opt. Commun., Phys. Rev., IEEE J. Quant. Electron., J. Opt. Soc. Am., Applied Optics, J. Appl. Phys.. Also, he was a proposal reviewer for Army Basic Res. Committee, Natl. Research Council, NSF, and Dept. of Energy.

Most recently, this principal investigator was invited to be a guest editor for the Special Issue of "IEEE Journal of Quantum Electronics" on "Quantum and Nonlinear Optics of Single Atoms, Ions, and Electrons." He was also invited to present an invited talk *("Relativistic Nonlinear Optics of a Single Electron")* at the International Conference on Quantum Electronics (May '87, Baltimore), as well as invited talks on various topics at a few other conferences during this year.

In the Spring of 1987, this principal investigator was elected a Fellow of the Optical Society of America.

In 1985-87 this principal investigator presented more than twenty invited lectures and seminars at M.I.T and other universities as well as at Bell Labs and other research institutions on various subjects directly related to my research. Some of them were related to more general subjects, in particular an invited cours (6 hours) at the University of Alabama at Huntsevill on "SDI and Soviet research on quantum electronics" and invited talk at the Harvard conference on "Soviet response to SDI".

The research by this principal investigator done basically under support of AFOSR, is well recognized by the research community in the field and extensively used by other workers; his work was refered more than 150 times in 1985-86 by other workers, according to "Science Citation Index" (only the papers in which this investigator is either the only or the first author, were counted).

Work published under the AFOSR Grant #85-0006, 1st and 2nd years

(i) Serial Journal Articles (published)

(1) A. E. Kaplan and S. Datta, "Soft X-ray Emission Excited by Electron Beams in a Superlattice," J. Luminescence, 31: 690-692 (1984).

(2) S. Datta and A. E. Kaplan, "Quantum Theory of Spontaneous and Stimulated Resonant Transition Radiation," Phys. Rev. 31 :790-796 (Febr. 1985).

(3) A. E. Kaplan and C. T. Law, "Isolas in four-wave mixing optical bistability," IEEE J. Quan. Electr. QE-21 : 1529-1537 (Sept. 1985).

(4) A. E. Kaplan, "Multistable self-trapping of light and multistable soliton pulse propagation." IEEE J. Quan. Electr. QE-21 : 1538-1543 (Sept. 1985).

(5) A. E. Kaplan, "Ultimate bistability: hysteretic resonance of a slightly- relativistic electron," IEEE J. Quan. Electr. QE-21 :1544-1549 (Sept. 1985).

(6) A. E. Kaplan, "Bistable solitons," Phys. Rev. Lett. 55 :1291-1294(16 Sept. 1985).

(7) *A. E. Kaplan, "Hysteretic resonance of a slightly relativistic single electron, "Nature," 317 : 476-477(10 October 1985); (*invited paper).

(8) E. M. Wright, P. Meystre (Max-Planck-Inst. Quantenoptik, Germany), W. J. Firth (Heriott-Watt Univ., Scotland, U.K.), and A. E. Kaplan (Purdue Univ.), "Theory of the nonlinear Sagnac effect in a fiber optic gyroscope", Phys. Rev. A. 32 :2857-2863 (November 1985).

(9) A. E. Kaplan, "Relativistic nonlinear optics of a single cyclotron electron", Phys. Rev. Lett. 56 :456-459 (February 3, 1986).

(10) D. R. Andersen, L. A. Kolodziejski, R. L. Gunshor, S. Datta, A. E. Kaplan (Purdue Univ.), and A. V. Nurmikko (Brown Univ.), "Nonlinear Excitonic Absorption in (Zn,Mn)Se Superlattices and ZnSe Films," Appl. Phys. Lett. 48 : 1559-1561 (9 June, 1986).

(11) A. E. Kaplan "Response to Comments by Enns and Rangnekar, "Phys. Rev. Lett. 57 : 779 (11 August, 1986).

(12) R. H. Enns and S. S. Rangnekar (Simon Fraser Univ., Canada) and A. E. Kaplan (Purdue Univ.), "Robust Bistable Solitons of the Highly-nonlinear Schrodinger Equation," Phys. Rev. A., Rapid Communications 35 :466-469 (1 Jan. 1987)

(13) D. H. Auston (AT&T Bell Labs), T. K. Gustafson (NSF), A. E. Kaplan (Purdue Un.), P. L. Kelley (MIT Lincoln Lab), and Y. R. Shen (Un. California, Berkeley), "Limits on nonlinear optical interaction", in review paper "Research on Nonlinear Optical materials: an assessment", Applied Optics, 26 : 211-234 (15 Jan. 1987).

(14) A. E. Kaplan, "Optical high-order subharmonic excitation of free cyclotron electrons," Optics Letters, 12: 489-491 (July 1987).

(15) F. Marquis, P. Meystre, E. M. Wright (OSC, Univ. Arizona), and A. E. Kaplan (Purdue Univ. Johns Hopkins Univ.), "Dynamics of the optical Freedericksz transition" Phys. Rev. 36A: 875-887 (July 15, 1987).

(16) R. H. Enns, S. S. Rangnekar (Simon Fraser Univ.), and A. E. Kaplan (Johns Hopkins Univ.), "Bistable soliton pulse propagation: stability aspects,"Phys. Rev. 36A: 1270-1278 (August 1, 1987).

(ii) Conference Proceedings

(17) A. E. Kaplan and S.Datta, "Extreme-ultraviolet and x-ray emission and amplification of nonrelativistic electron beams traversing a superlattice", in "*Laser Technique in the Extreme Ultraviolet*", editors S.E.Harris and T.B.Lucatorto, (Am. Inst. Phys., NY, 1984), pp. 304-310.

(18) A. E. Kaplan, "Multiphon excitation of relativistic cyclotron resonance and phase bistability," in "*Optical Bistability III*," ed. by H.M. Gibbs, P. Mandell, N. Peighambarian, and S. D. Smith, Springer-Verlag, Berlin, 1986, pp. 240-243.

(19) A. E. Kaplan and C. T. Law, "Eigenpolarizations, nonreciprocity, and "isolas" multistability in degenerated four-wave mixing," in SPIE Conf. Proceedings on Nonlinear Optics and Applications, 1986, v. 613, pp.100-105.

(20) C. T. Law and A. E. Kaplan, "Low Relativistic Electron Beams Traversing a Superlattice as a X-ray Source," Am. Inst. Phys. Conf. Proc. No. 147, "Short Wavelengths Coherent Radiation: Generation and Applications," (Am. Inst. Phys., N.Y., 1986), pp. 27-33.

(21) I. C. Khoo, R. R. Michael, T. H. Liu, G. Finn (Pennsylvania State Univ.), and A. E. Kaplan (Purdue Univ.), "Optical limiting using self-focusing and self-bending of light by a nematic liquid crystal film," SPIE, Nonlinear Optics and Applications, 613: 43-47 (1986).

(iii) Conference Papers

(22) A. E. Kaplan, "Polarization Dragging in Degenerated Four-Wave Mixing," Ann. Meet. Opt. Soc. Am., (Oct. 29-Nov. 2, 1984, San Diego); J. Opt. Soc. Am. A, 1: 1262 (1984).

(23) A. E. Kaplan and S. Datta, "X-ray emission by electron beams in superlattices," ibid; J. Opt. Soc. Am. A, 1: 1246 (1984).

(24) A. E. Kaplan, "Bistable soliton pulses and bistable self-trapping of light," CLEO-85, Baltimore, Maryland, May 21-24, 1985, paper Tu M4.

(25) A. E. Kaplan and C. T. Law, "Multiple isolated branches in four-wave mixing optical bistabilty." Intern. Meeting on Instabilities and Dynamics of Lasers and Nonlinear Opt. Systems, Univ. Rochester, Rochester, N.Y., June 18-21, 1985.

(26) A. E. Kaplan, "Semi-surface waves at nonlinear interfaces with arbitrary nonlinearities", 2nd Intern. Conf. on Surface Waves, Yugoslavia, October 1985.

(27) A. E. Kaplan, "Three-photon optical excitation of a slightly- relativistic single electron", 1985 Ann. Meeting of Opt. Soc. Am., Washington, DC (Oct 14-18, 1985); J. Opt. Soc. Am. A 2(13) :P86(1985).

(28) A. E. Kaplan, "Subharmonic phase memory: symmetric optical multistability", Int. Meeting on Optical Bistability, Tucson, AZ(Dec.2-4, 1985).

(29) D. R. Anderson, R. L. Gunshor, S. Datta, A.E. Kaplan, and L. A. Kolodziejski, "Nonlinear excitonic absorption of (Zn,Mn)Se superlattices", Mat. Res. Soc. Symp. on Nonlinear Optical Materials, Boston, MA (Dec. 2-6,1985).

(30) A. E. Kaplan, "Eigen-polarizations, light-induced nonreciprocity, and "flying saucers" in four-wave mixing" SPIE Conf. on Nonlinear Optics and Applications, 19-24 January 1986, Los Angeles.

(31) C. T. Law and A. E. Kaplan, "Soft X-ray radiation from low relativistic beams..." 1986 Topical Meeting on Short Wavelength Coherent Radiation, March 24-27,1986, Monterey, CA.

(32) *A. E. Kaplan, "Fundamental limits on nonlinear refractive index in resonant excitations," Workshop on Nonlinear Optics Materials, Annapolis, MD, April 27-29, 1986 (*invited panel presenation).

(33) A. E. Kaplan and C.T.Law, "Isolas" multistability in counter-propagating beams of light," SPIE Conf. on Optical Chaos, 2-6 June 1986, Quebec, Canada.

(34) A. E. Kaplan and C. T. Law, "Four-wave mixing isolas," CLEO'86, June 9-13, San Francisco, CA.

(35) A. E. Kaplan, "Relativistic nonlinear optics of a single electron," Int. Quant. Electr. Conf. '86, June 9-13, San Francisco, CA; J. Opt. Soc. Am. B, 3 : P216(August 1986).

(36) C. T. Law and A. E. Kaplan, "Free electron X-ray source based on solid-state superlattice, "IQEC '86, ibid; J. Opt. Soc. Am. B, 3 : P128 (August 1986).

(37) A. E. Kaplan and Y. J. Ding "Hysteretic three-photon excitation of a cyclotron resonance in semiconductors," 1986 Ann. Meet. Opt. Soc. Am. (Oct. 19-24, 1986).

(38) A. E. Kaplan, "Optical Subharmonic Excitation of Free Cyclotron Electronics," ibid.

(39) A. E. Kaplan and C.T. Law, "Ultra-narrow lines of X-ray radiation of Electron Beams in a Solid-state Superlattice, "ibid.

(40) G. Swartzlander and A. E. Kaplan, "Self Deflection of a Light Beam in a Thin Nonlinear Film," ibid.

(41) A. E. Kaplan, "SDI and Soviet Quantum Electronics", Harvard Conference on "Soviet Response to SDI", Harvard Univ., Cambridge, MA, December 1986), invited paper.

(42) *A. E. Kaplan, "Bistable and robust solitons of highly-nonlinear Schrodinger equations", the Workshop "State of the Art Developments in Nonlinear Optics" (March 1987, Tucson, AZ). (*Invited paper)

(43) *A. E. Kaplan, "Nonlinear Optics of a Single Electron," Int. Quant. Elect. Conf. (Baltimore, May 1987) (*invited paper).

(44) Y. J. Ding and A. E. Kaplan "High-Order Multi-Photon Optical Excitation of Free Cyclotron Electrons," Intern. Conf. Quant. Electr., IQEC (Baltimore, May 1987).

(45) *A. E. Kaplan, "Bistable solitons and their application in Nonlinear Optics", the Sixth Intern. Conference on Mathematical Modeling (August 1987, St. Louis, MN). (*Invited paper)

(46) *A. E. Kaplan, "Nonlinear optics of a single electron," XXII General Assembly of the International Union of Radio Science (URSI) (Tel Aviv, Israel, August 24-Sept. 4, 1987). (*Invited paper)

(iv) Pending publications

(47) V. S. Butylkin, A. E. Kaplan, Yu. G. Khronopulo, and E. I. Yakubovich, "*Resonant nonlinear interactions of light with matter,*" monograph, to be published by Springer-Verlag in 1987; translated from Russian, with new chapters added.

(48) A. E. Kaplan, "Enhancement of laser gyroscope based on nonreciprocal feedback," submitted for publication.

(49) A. E. Kaplan, "Light-induced polarization dragging in degenerated four-wave mixing," submitted for publication.

(50) A. E. Kaplan and C. T. Law, "X-ray narrow-line source based on transition radiation of low energy electron beams traversing a superlattice", submitted for publication.

END
DATE
FILMED
4-88
DTIC