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MASTER

LASERS FOR ISOTOPE SEPARATION *

Final Report

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Marlan O. Scully

Optical Sciences Center
University of Arizona
Tucson, Arizona 85721

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ABSTRACT

Research has been carried out on laser systems and materials with potential applications in schemes for laser isotope reparation. Theoretical studies have been made of both the linear and strong-signal properties of the free-electron laser, a device which is tunable and potentially capable of high power output. Spontaneous laser action in laser isotope separation has been studied. Ultrafast relaxation of the electron-hole distribution in semiconductors, such as germanium, has been probed experimentally by means of high-power picosecond laser pulses and has been analyzed theoretically.

FINAL REPORT

A. The Free-Electron Laser

The free-electron laser, (FEL) because of its tunability and potential for high average power output, is of interest as a device for use in laser isotope reparation. Our studies have shown that the FEL is a classical device which operates by stimulated scattering. This scattering is associated with a bunching of the electron distribution at optical wavelength. We have obtained the small-signal gain of the device (Paper I of the enclosed reprints). The strong-signal properties of the FEL have been obtained by means of a harmonic expansion of the electron distribution function, which results in a set of "quasi-Bloch" equations. Saturation-detuning curves for the FEL are obtained (Paper 2). The electron recoil in the FEL (which leads to gain) is found to be accompanied by a spreading of the electron distribution, which can be large compared to the recoil (Paper 3). This spreading creates difficulties for schemes to improve the efficiency of the FEL by recirculating the electrons in a storage ring. Our work on the FEL was discussed at a symposium at the Redstone Arsenal, Alabama, in 1976 (Paper 4) and is treated at length in Paper 5, which is based on lectures given at the 1977 Physics of Quantum Electronics conference in Telluride, Colorado. Paper 5 also discusses the possibility of using an effect analogous to photon echo to improve the efficiency of the FEL.

B. Spontaneous Laser Action in Laser Isotope Separation

Schemes for laser isotope separation by means of multistep photoionization involve production of selective populations of excited

atoms in intermediate states. In Paper 6 we investigate the conditions under which undesirable spontaneous laser action in LIS systems may act to de-excite inverted populations of atoms.

C. Line Narrowing in a Symmetry Broken Laser

We consider (Paper 7) the quantum theory of a laser into which is injected a small fraction of the output from a "master laser". This external "symmetry-breaking" field is found to suppress phase fluctuations, so as to narrow the spectral output of the laser. The effect is similar to the line narrowing associated with the Lamb-Mössbauer effect.

D. Ultrafast Processes in Semiconductors

We have used intense picosecond pulses from a mode-locked Nd:glass laser to probe the nonlinear nonequilibrium properties of the electron-hole distribution in germanium (Paper 8). We measure the transmission of single pulses as a function of incident pulse energy and temperature of the Ge sample. We also measure the transmission of a weak probe pulse as a function of time delay after an excitation pulse, thus determining the relaxation rate of the solid-state plasma. The processes governing the generation and subsequent transient behavior of the plasma have been analyzed, and a first-principles theory has been developed which yields results in good agreement with experiment (Paper 9). The photoluminescence spectra of Ge at high excitation intensities have been measured and accounted for theoretically (Paper 10).

List of Publications Produced Under This ERDA Contract

1. F. A. Hopf, P. Meystre, M. O. Scully, and W. H. Louisell, "Classical theory of a free-electron laser," Opt. Commun. 18, 413 (1976).

2. F. A. Hopf, P. Meystre, M. O. Scully, and W. H. Louisell, "Strong-signal theory of a free-electron laser," Phys. Rev. Lett. 37, 1342 (1976).

3. H. Al-Abawi, F. A. Hopf, and P. Meystre, "Electron dynamics in a free-electorn laser," Phys. Rev. A16, 666 (1977).

4. F. A. Hopf and P. Meystre, "Theoretical Development of the free-electron laser," in Cooperative effects in matter and radiation, edited by Charles M. Bowden, D. W. Howgate, and Hermann R. Robl (Plenum, New York, 1977), p. 291.

5. Frederic A. Hopf, Pierre Meystre, Gerald T. Moore, and Marlan O. Scully, "Novel Sources of Coherent Radiation," in Free-electron generators of coherent radiation, The Physics of Quantum Electronics Vol. V (Addison-Wesley, Reading, Mass., 1978) p. 41.

6. C. D. Cantrell, Frederic A. Hopf, George W. Rhodes, and Marlan O. Scully "Spontaneous laser action in laser isotope separation," Appl. Opt. 15, 1651 (1976).

7. Weng W. Chow, Marlan O. Scully, and Eric W. Van Stryland, "Line narrowing in a symmetry broken laser," Opt. Commun. 15, 6 (1975).

8. A. L. Smirl, J. C. Matter, A. Elci and M. O. Scully, "Ultrafast relaxation of optically excited nonequilibrium electorn-hole distributions in germanium," Opt. Commun. 16, 118 (1976).

9. A. Elci, M. O. Scully, A. L. Smirl, and J. C. Matter, "Ultrafast transient response of solid-state plasmas. I. Germanium, theory, and experiment," Phys. Rev. B16, 191 (1977).

10. H. M. van Driel, A. Elci, J. S. Bessey, and Marlan O. Scully, "Photo-luminescence spectra of germanium at high excitation intensities," Solid State Commun., 20, 837 (1976).

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