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INTERACTION OF X-RAY RADIATION WITH MATTER.(U)
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Final Scientific Report

Grant AFOSR-76-2933

Interaction of X-ray Radiation with Matter

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Air Force Office of Scientific Research

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Pasadena, California

Principal Investigator: A. Yariv

February 10, 1978

Summary of Technical Work

1. Introduction

The research program concerned itself mainly with the prospect of achieving x-ray radiation by the interaction of high energy electron beam in solids or in other structures and media.

The main motivation is the desire to extend the coherence properties available at low frequencies from microwave oscillators (gun effect, traveling wave tube, etc) and at higher (optical) frequencies from laser oscillators to the x-ray region of the spectrum.

An attempt in this direction requires a thorough understanding of the physical principles involved, which in turn make it possible to evaluate the propose schemes for achieving the desired goal.

In the work reported, we investigated theoretically two different approaches: (1) laser type devices; (2) traveling wave interaction. We shall consider them in turn, in the following.

2. X-ray Lasers

The possibility of achieving x-ray laser action in the 1-100Å wavelength region was considered using detailed laser theory and specific x-ray physical data. The conclusion is that, due to the immense pump power requirements (which in turn are due to the extremely short lifetime 10^{-12}-10^{-15}s of x-ray states) the prospects for x-ray lasers are not bright. When they will be built they will very likely employ extremely short pulses and will be pumped by mode-locked lasers. The pump power scales as $\sim \lambda^{-5}$ so that the first lasers will probably emit soft x-rays ($\sim$ 100Å). Detailed analysis and numerical data are included in Ref. 1.

We have also addressed ourselves to the problem of the x-ray resonator, since conventional laser resonators employing mirrors are probably not practical. We have proposed and analyzed the use of periodicity in either natural crystals or artificial layered periodic media to provide oscillation feedback via the mechanism of distributed feedback. We believe this approach to be one of the few feasible solutions to these problems. Full details are included in Refs. 2 and 3.

3. Interaction of X-rays and Electron Beams

Another physical mechanism capable of amplifying x-ray radiation is the interaction with energetic electrons. This interaction can take place in vacuum as in microwave traveling wave tubes (TWT) or in solids. What was completely lacking when we started this work was any understanding of the basic physics. Especially there was a lack of awareness that the basic ideas have already been worked out by electrical engineers in the 40s and 50s in connection with TWT devices. In a series of publications (Refs. 3,4,5) we extended the TWT theories to describe the x-ray regime. We showed the connection between the Stanford relativistic beam laser and that of earlier theories, and considered the case of collective and single electron interactions.

A key concept in all the beam devices is that of the periodicity of the medium and of the interaction impedance. The periodicity is needed to obtain cumulative interaction over the device length, thus insuring a continuous power flow from the electron to the beam. This can be achieved by a periodic structure such as the helix in TWT, periodic dc magnetic field (Stanford laser), waveguide corrugations (our proposal), or natural and artificial crystal periodicity (our work).

Each of these solutions requires a characterization of the strength of the interaction which is usually expressed by means of the interaction impedance. We have introduced this concept (long familiar to the TWT fraternity) to the optics field, and obtained expressions for it in a number of important cases.

We have studied in some detail (Ref. 5) the case of traveling wave interaction inside solids. Such a device could be built using doped semiconductor with periodic surface corrugation to provide the necessary periodicities. Our conclusions are not encouraging. The effect of collisions and finite temperature raise the threshold currents to unrealistically high values.

Conclusion: We conclude that free electron lasers, i.e., beam devices operating in vacuum, offer the best chance of realizing viable tunable x-ray sources in the near future.

Interactions with Other Groups

We have and are continuing to interact on a regular basis with other groups active in this area. These include the groups at Stanford, U.S.C., and at the Optical Sciences Center, Tuscon, and with Professor Das Gupta at Texas Tech. We have presented a paper on our work at the Amsterdam International Quantum Electronics Conference in 1976.

We have published five articles on the general subject of x-ray lasers and electron beam devices. A list follows.

Published Articles

Amnon Yariv, "Some feasibility considerations of x-ray laser action", Optics Comm. 22, 1 (1977).

Amnon Yariv and Pochi Yeh, "X-ray laser oscillation in artificial layered media", Optics Comm. 22, 5 (1977).

Avraham Gover and Amnon Yariv, "Monolithic solid-state traveling-wave amplifier", J. Appl. Phys. 45, 2596 (1974).

A. Gover and A. Yariv, " Intraband radiative transitions and plasma-electromagnetic-wave coupled in periodic semiconductor structure", J. Appl. Phys. 46, 3946 (1975).

A. Gover, K. H. Burrell and A. Yariv, "Solid-state traveling-wave amplification in the collisionless regime", J. Appl. Phys. 45, 4847 (1974).

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This research pertains to the prospect of achieving X-ray radiation by the interaction of high energy electron beam in solids or in other structures and media.

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