XI. ELECTRODYNAMICS OF MEDIA*

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

The research on interaction of electromagnetic fields with media is pursued (a) to obtain self-consistent formulations of electrodynamics in the presence of moving and deforming media, and (b) to study nonlinear interactions of electromagnetic fields and optical frequencies both theoretically and experimentally.

1. Force on Media in Electromagnetic Fields

The methods developed for the determination of the force distribution in media that can be polarized and magnetized are being applied to media with dispersion and quadrupolar media. The work is relevant to an understanding of electroacoustic interactions both at microwave and optical frequencies. It has been found that the energy momentum tensor of media that are dispersive may be asymmetric. The asymmetry has been interpreted.

Also under study are quantum descriptions of electromagnetic fields in dispersive and/or moving media. Quantum effects are important, particularly in determining the noise of optical devices.

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2. Nonlinear Interactions at Optical Frequencies

One objective of this program is to produce short powerful pulses of radiation in the infrared. Work is progressing on cavity dumping of a transverse excited atmospheric pressure CO_2 laser oscillator. Our eventual aim is to combine the cavity dumping with mode locking to obtain a single subnanosecond pulse.

For a better understanding of saturation of CO_2 lasers, studies are conducted experimentally and theoretically on cross-relaxation phenomena in low-pressure and high-pressure discharges.

The HF laser is being studied experimentally because its very high gain allows the study of nonlinear gain phenomena in a very short system.

The relatively simple pumping processes of diatomic molecules, and the promise of very high efficiency from cw CO lasers make this system attractive for study.

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The aim is to develop a computer model for the system so as to be able to predict the efficiency of the system as a function of gas mixtures and geometry.

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3. Waves in Bianisotropic Media

A bianisotropic medium becomes magnetized when placed in an electric field, and electrically polarized when it is placed in a magnetic field. In terms of constitutive relations, the D-field vector is dependent on both the E-field and the B-field vectors, and so is the H-vector. This class of media includes moving media, and magnetoelectrics as special cases.

Little is known about how an electromagnetic wave behaves inside these media. Studies should be made in order to consider potential applications of this new class of materials to devices other than those proposed for computer memories.

Prior work on the interaction of electromagnetic waves with material media has been based on the quantum-mechanical aspects of the media. As far as we know, no such studies have been made on bianisotropic media. We propose to study this problem with emphasis on the quantum-mechanical aspects of the electromagnetic field.

J. A. Kong

4. Fiber Optics

Fiber optics has many applications. In communication it is a potential candidate for picture phones and wideband transmission media. In medicine it has applications for endoscopy and probes, and in high-speed photography for image dissection. Nevertheless our theoretical understanding of fiber optics is limited to our understanding of dielectric waveguides. Considerable effort has been expended to find less absorbing media to make the fibers. To obtain better internal total reflection, a graded index of refractions has been used. As an effective transmitting medium, recently reported fibers have achieved 20 dB/km. We still need to learn how cross-sectional geometry and mutual coupling of fibers affects transmission. We propose to study light propagation characteristics of various media, their inhomogeneities, the fiber geometry, and mutual coupling phenomena of these optical waveguides.

J. A. Kong

5. Environmental and Geophysical Studies

Pollution problems have attracted much public attention. Electromagnetic wave propagation studies can be used to investigate a wide variety of problems such as the global distribution of pollutants in air and water, oil slicks, and marine surface life in the ocean. They can also be used to investigate the effects of tall buildings on TV signals. In terms of electromagnetic wave radiation studies, earth resources and geophysical structures can be probed by an antenna. Subsurface probing of lunar electrical properties may give an indication of the structure, the history and the origin of the moon. In all such studies, the model is a stratified medium. We propose to evolve theoretical models of various radiation, propagation and scattering phenomena which would apply to such physical situations.

J. A. Kong

A. INPUT POWER, GAIN, AND OUTPUT OF A TRANSVERSELY EXCITED ATMOSPHERIC (TEA) CO_2 LASER

We have been studying the characteristics of the TEA CO_2 laser. Our aim in these experiments was not to establish a parametric profile of the laser, but rather to collect a detailed set of data relating to a single TEA discharge tube and a small set of operating parameters. This information will be used to evaluate the analytic model that we are developing,[1] as well as to provide some empirical input to it.

All measurements were performed with the use of a TEA CO_2 discharge tube of the following description.[2]

Material:	Plexiglas tube, 5 cm OD
Overall length:	90 cm
Cathode:	170 pins, spaced 0.5 cm apart, in line
Anode:	170 1-kΩ resistors, similarly arranged as pins and diametrically opposed.

The experimental arrangement for pulsing the discharge was the same in all cases: a spark-gap trigger circuit with 0.025 μF capacitance charged to 19 kV. Stray inductance was reduced more than in our previous designs, with a resulting reduction in current pulse rise-time and duration. The tube was not pulsed repetitively, but was run single-shot with intervals of more than 30 sec.

The total pressure in the tube was maintained at 350 Torr. Total flow rate of gas through the tube was held at 2 liter-atm/min. The only parameter that we varied was the mixture of component gases. In the first set of measurements the mixture was 6:1 :: He:CO_2. In the second set the mixture was 12:2:1 :: He:CO_2:N_2. These parameter sets were chosen, after preliminary testing,[3] to achieve reasonably high gain and a well-behaved discharge (few high-current arcs).

Three quantities were measured as a function of time.

1. Electrical Input Power

Current flow through the tube was measured by an HP-1111a current probe. The probe monitored current in a No. 32 copper wire shunt parallel to the main current path. Voltage between the electrodes was measured with a Tektronix Type P6015 high-voltage probe. The product of current and voltage, after excluding losses to the 1-kΩ resistors, is presented as input power measured in megawatts.

2. Small-Signal Gain

We can relate the small-signal gain of the medium to occupancy of certain CO_2 vibrational states. Assuming intensities far below saturation intensity and 10μ-P(20) input radiation, we may write the following approximate expression relating output to input intensity.[4]

$$\frac{I_o}{I_{in}} = \exp L\left(\frac{405}{\sqrt{T_g}}\right)\left(\frac{.64}{\sqrt{T_g}}\right)\left(\frac{f_{CO_2}}{f_{CO_2} + .7\, f_{He} + .75\, f_{N_2}}\right)(N_{001} - N_{100}).$$

Here $.64/\sqrt{T_g}$ represents the fraction of particles in the 001 and 100 vibrational states which are also in the rotational states linked by the induced transitions, and

L = effective length (cm) of the amplifying medium

f_i = fraction of gas that comprises the i^{th} species

$$N_{\alpha\beta\gamma} = \frac{\text{Number of } CO_2 \text{ molecules in } \alpha\beta\gamma \text{ vibrational state}}{\text{Total number of } CO_2 \text{ molecules}}$$

T_g = translational temperature of the gases.

The gain factor is defined as

$$\alpha \triangleq \ln\left(\frac{I_o}{I_{in}}\right) = L\,\frac{260}{T_g}\left(\frac{f_{CO_2}}{f_{CO_2} + .7\, f_{He} + .75\, f_{N_2}}\right)(N_{001} - N_{100}).$$

Probe apparatus similar to that described by Elkind and Hoff[5] was used to measure α. Detection of signals was accomplished in a Faraday cage with a Ge:Au detector.

3. Laser Output Power

An electromagnetic cavity was constructed and aligned. The discharge tube was utilized as an active element. The cavity may be described as follows.

Mirrors – 4 m radius, high reflectivity, Silicon substrate
4 m radius, 20% transmissivity, Germanium substrate

Length – 1.7 m

Internal aperture – 30 cm from HR mirror, 1-cm diam.

The generated optical pulses were attenuated by a factor of 1000 approximately, and then detected with a Ge:Au device. It was established through monochromator measurements that the radiation was 10μ-P(20) in all instances.

All quantities have been plotted against time (μs). The origin of the time axis was determined by the beginning of the current discharge pulse. The oscilloscope was dual-beam Tektronix Type 556.

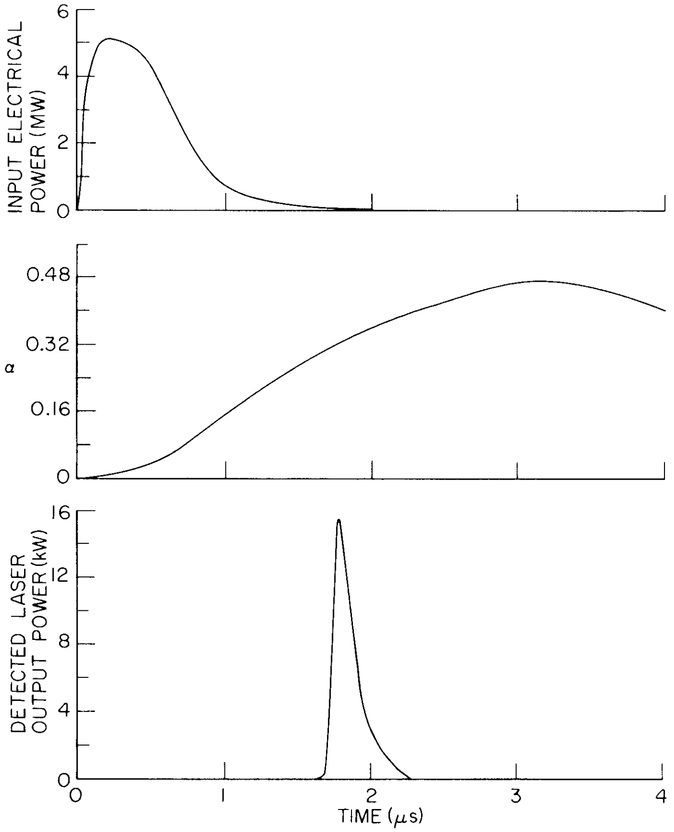

Fig. XI-1.
Measurements for 6:1 mixture.

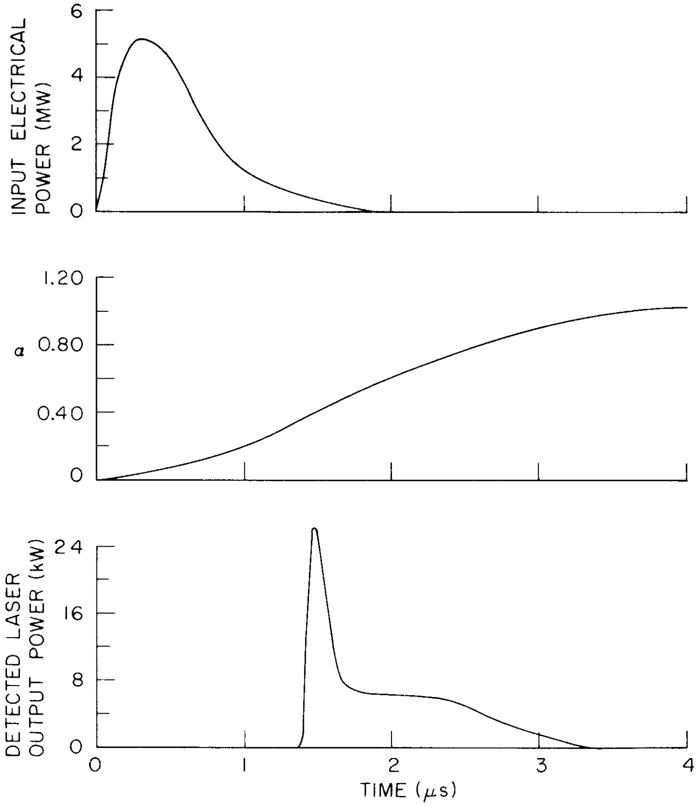

Fig. XI-2.
Measurements for 12:2:1 mixture.

Figure XI-1 deals with the 6:1 :: He:CO_2 gas mixture. In Fig. XI-1 the three measured quantities are displayed against a common time axis. Figure XI-2 involves the 12:2:1 :: He:CO_2:N_2 gas mixture, showing all three quantities with high resolution.

Some obvious differences are evident in these two figures. Addition of N_2 causes only a slight increase in laser pulse height, but adds a significant "tail" to the waveform. The peak value of gain is twice as large for the gas mixture with N_2 as without it. Also, we have found that the full width at half-maximum for α is approximately twice as large for He:CO_2:N_2 as for He:CO_2.

D. L. Lyon

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