

OPTICAL MASERS

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Ever since the first demonstration of microwave amplification by the use of stimulated emission, there has been speculation as to whether or not the maser concept could be successfully applied in the infrared and visible portion of the electromagnetic spectrum. As early as 1956, R. H. Dicke proposed¹ a means of making an ammonia-beam maser in the infrared, using the rotational energy levels of the ammonia molecule. In the past few years, people have been optimistic about extending maser techniques into the visible portion of the spectrum. The basic principles underlying all masers—microwave, infrared, and visible—are the same,² but the problems that arise in achieving practical embodiments of the maser concept differ radically as one goes from the microwave frequency region (10^9 to 10^{11} cps) to the visible range (frequencies of 10^{14} to 10^{15} cps). These concepts are discussed here, as in the current state of the art and some possible applications.

Two examples will illustrate the changes required in increasing the frequency by four orders of magnitude, i.e., in going from the microwave to the visible range of the spectrum.

One is the resonant structure required to concentrate the electromagnetic field. At microwave frequencies, wavelengths are of the order of a centimeter, and cavities can be built that are one, or at most a few, half-wavelengths long. The modes of the resonator are generally well resolved, and it is no problem to couple the excitative material to the desired cavity mode. Optical wavelengths, on the other hand, are so small that it is impossible to build useful structures a few wavelengths across, and much larger structures must be employed. These large structures can be expected to sustain many modes very close together in frequency and of comparable Q . Moding may thus be a serious problem in optical masers, whereas it is not of concern at microwave frequencies.

A second example of a new problem raising at optical frequencies is that due to spontaneous emission. Atoms in excited states tend to return

to their lowest energy (ground) state by the emission of radiation. This process has two harmful effects in a maser: it provides an alternative method of de-excitation, reducing the size of the population excess in the upper state; and the spontaneously radiated energy, being incoherent with the signal wave field, is an additional source of noise in a maser amplifier or oscillator.

Neglecting possible coherence effects in spontaneous emission, a system having N_2 atoms in excited states will lose energy by spontaneous emission at a rate (P_{sp}):

$$P_{sp} = \frac{4\omega^3 \mu^2 N_2}{3c} \quad (1)$$

Where: ω is the circular frequency of the radiation, μ is the dipole moment associated with the transition between the ground and excited states, and c is the velocity of light.

By comparison, the power (P_{st}) radiated by a system with ΔN atoms in the "excess" upper state population due to stimulated emission is:

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Table of Contents Optical Masers

1. Understanding the eBook Optical Masers
 - The Rise of Digital Reading Optical Masers
 - Advantages of eBooks Over Traditional Books
2. Identifying Optical Masers
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Optical Masers
 - User-Friendly Interface
4. Exploring eBook Recommendations from Optical Masers
 - Personalized Recommendations
 - Optical Masers User Reviews and Ratings
 - Optical Masers and Bestseller Lists
5. Accessing Optical Masers Free and Paid eBooks
 - Optical Masers Public Domain eBooks
 - Optical Masers eBook Subscription Services
 - Optical Masers Budget-Friendly Options
6. Navigating Optical Masers eBook Formats

- ePub, PDF, MOBI, and More
- Optical Masers Compatibility with Devices
- Optical Masers Enhanced eBook Features

7. Enhancing Your Reading Experience

- Adjustable Fonts and Text Sizes of Optical Masers
- Highlighting and Note-Taking Optical Masers
- Interactive Elements Optical Masers

8. Staying Engaged with Optical Masers

- Joining Online Reading Communities
- Participating in Virtual Book Clubs
- Following Authors and Publishers Optical Masers

9. Balancing eBooks and Physical Books Optical Masers

- Benefits of a Digital Library
- Creating a Diverse Reading Collection Optical Masers

10. Overcoming Reading Challenges

- Dealing with Digital Eye Strain
- Minimizing Distractions
- Managing Screen Time

11. Cultivating a Reading Routine Optical Masers

- Setting Reading Goals Optical Masers
- Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Optical Masers

- Fact-Checking eBook Content of Optical Masers
- Distinguishing Credible Sources

13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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