

# 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 proposed<sup>1</sup> 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,<sup>2</sup> but the problems that arise in achieving practical embodiments of the maser concept differ radically as one goes from the microwave frequency region ( $10^3$  to  $10^{11}$  cps) to the visible range (frequencies of  $10^{14}$  to  $10^{16}$  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 emissive 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. Mixing 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 arising 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 ( $P_{sp}$ ):

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

Where:  $\omega$  is the circular frequency of the radiation,  $\mu$  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  $\Delta N$  atoms in the "excess" upper state population due to *stimulated emission* is:

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