6

Types of Lasers

6.1 INTRODUCTION

This chapter contains miscellaneous data and practical information about a number of lasers. It should be pointed out that there are many more lasers in existence than just those described here. This chapter, however, concentrates on those types which are most commonly used and whose characteristics are representative of a whole category of lasers. It should also be noted that some of the data presented in this chapter (for example, on output powers and energies) are likely to be rapidly superseded. These data are, therefore, presented only as a rough guide.

We will consider the following types of lasers: (1) solid-state (crystal or glass) lasers, (2) gas lasers, (3) dye lasers, (4) chemical lasers, (5) semiconductor lasers, (6) color-center lasers, and (7) free-electron lasers.

6.2 SOLID-STATE LASERS

The term solid-state laser is usually reserved for those lasers having as their active medium either an insulating crystal or a glass. Semiconductor lasers will be considered in a separate section since the mechanisms for pumping and for laser action are quite different. Solid-state lasers often use as their active species impurity ions introduced into an ionic crystal. Usually the ion belongs to one of the series of transition elements in the periodic table (e.g., transition metal ions, notably Cr$^{3+}$, or rare earth ions, notably Nd$^{3+}$ or Ho$^{3+}$). The transitions used for laser action involve states
belonging to the inner unfilled shells. These transitions are therefore not so strongly influenced by the crystal field. This in turn means that the transitions are quite sharp (i.e., $\sigma$ reasonably large) and the nonradiative channels are fairly weak (i.e., $\tau$ reasonably long). Consequently the threshold pump rate ($W_p \propto 1/\sigma \tau$ for a four-level laser) is low enough to allow laser action.

6.2.1 The Ruby Laser$^{(1)}$

This type of laser was the first to be made to operate,$^{(2,3)}$ and still continues to be used. Ruby, which has been known for hundreds of years as a naturally occurring precious stone, is a crystal of $\text{Al}_2\text{O}_3$ (corundum) in which some of the $\text{Al}^{3+}$ ions are replaced by $\text{Cr}^{3+}$ ions. As a laser material, it is usually obtained by crystal growth from a molten mixture of $\text{Cr}_2\text{O}_3$ ($\sim 0.05\%$ by weight) and $\text{Al}_2\text{O}_3$. The laser energy levels are those of the $\text{Cr}^{3+}$ ion in the $\text{Al}_2\text{O}_3$ lattice, and the main levels of interest are indicated in Fig. 6.1. Laser action usually occurs on the $\overline{E} \rightarrow ^4A_2$ transition ($R_1$ line, $\lambda_1 \approx 694.3$ nm, red). Ruby has two main pump bands $^4F_1$ and $^4F_2$ centered at wavelengths of 0.55 $\mu$m (green) and 0.42 $\mu$m (violet), respectively. These bands are connected by a fast ($\sim 10^{-7}$ s) nonradiative decay to both $2\overline{A}$ and $\overline{E}$ states. Since these last two states are also connected to each other by a very fast nonradiative decay ($\sim 10^{-9}$ s), thermalization of their population occurs which results in the $\overline{E}$ level being the more heavily populated. The frequency separation between $2\overline{A}$ and $\overline{E}$ ($\sim 29$ cm$^{-1}$) is small compared to $(kT/h)$, and the $2\overline{A}$ population is comparable with the $\overline{E}$ level population. It is thus possible to obtain laser action on the $2\overline{A} \rightarrow ^4A_2$ transition also ($R_2$ line, $\lambda_2 \approx 0.6928$ $\mu$m) by using, for instance, the dispersive systems of Fig. 5.7. Despite the complication of having these two laser transitions, it is apparent that ruby operates as a three-level laser.

FIG. 6.1. Energy levels of ruby.