of 1.064 μm. (a) How many longitudinal modes will oscillate when the laser operates at room temperature? (b) What is the linewidth of an oscillating laser mode when the laser has an output power of 1 mW?

Solution (a) Only one longitudinal mode will oscillate above the laser threshold, for two reasons. First, Nd : YAG is predominantly homogeneously broadened at room temperature. Second, according to Example 11.1, the longitudinal mode spacing for this microchip laser is $\Delta\nu_{\mathrm{L}} = 164.8$ GHz, which is larger than the entire Nd : YAG linewidth of 150 GHz.

(b) The laser photon energy is $h\nu = (1.2398/1.064)$ eV $= 1.165$ eV. From Example 11.1, $\Delta\nu_{\mathrm{c}} = 91.91$ MHz. Because this laser is a four-level system, $N_{\mathrm{sp}} = 1$. From (11.65), we find the following Schawlow–Townes linewidth for the oscillating laser mode:

$$\Delta\nu_{\mathrm{ST}} = \frac{2\pi \times 1.165 \times 1.6 \times 10^{-19} \times (91.91 \times 10^{6})^{2}}{1 \times 10^{-3}} \times 1\ \mathrm{Hz} = 9.9\ \mathrm{Hz}.$$

Compared to the longitudinal mode width of 91.91 MHz for the cold cavity, this oscillating mode width is nearly seven orders of magnitude smaller. This linewidth-narrowing effect is caused by the coherent nature of the stimulated emission and is a fundamental feature of lasers. Note, however, that the Schawlow–Townes linewidth is only the theoretical lower limit of an oscillating laser mode. In practice, the linewidth of a laser is often broadened far above this limit by other mechanisms, such as fluctuations in the pump power and temperature, mechanical vibrations, and electronic noise from the circuit supporting the operation of the laser. The Schawlow–Townes limit can be approached only by making every effort to eliminate all external effects that broaden the laser linewidth.

11.3 Laser power

In this section, we consider the output power of a laser. Because the situation of a multimode laser can be quite complicated due to mode competition, we consider for simplicity only a homogeneously broadened, CW laser oscillating in a single longitudinal and transverse mode. Therefore, the parameters mentioned in this section are not labeled with mode indices because all of these parameters are clearly associated with the only oscillating mode being considered. The simple case of a Fabry–Perot cavity that contains an isotropic gain medium with a filling factor Γ as shown in Fig. 11.5 is considered. To illustrate the general concepts, we first consider the situation when the gain medium is uniformly pumped so that the entire gain medium has a spatially independent gain coefficient g. We then consider at the end of this section the case of optically pumped lasers, as also considered for the laser threshold in the preceding section, taking into account the longitudinal spatial dependence of the gain coefficient.