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# Estimation of Laser Linewidth

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**ABSTRACT**

The laser linewidth for 514.5nm, 501.7nm, 496.5nm, 488nm, 476.5nm has been estimated by applying the classical formula. The linewidth corresponding to various length of resonance cavity as well as for the various output power has been estimated for each value of he wavelength. We have used the formula $\Delta\omega_c = \frac{c\delta c}{2L}$ and $\Delta\omega_L = \frac{\hbar\omega 0.(\Delta\omega_c)^2}{2P}$ where $\Delta\omega_c$ is cavity resonance width $\Delta\omega_L$ is line width for the laser output and $\delta c$ = 1-$R_1 R_2$ where $R_1$ and $R_2$ are the power reflection coefficient of the cavity minors at the laser frequency.

**Keywords:** laser linewidth, output power, resonance cavity, laser frequency.

## 1. INTRODUCTION

The Ar atom has to be first ionized and them excited to higher energy levels of the ion. Because of the large energies involved in the $Ar^+$ laser discharge, is very intense, tapical valuesbeing 40A at 165 V. Another important properties of a laser is it ability to produce light of high spectral purity or high temporal coherence. The finite spectral width of a laser operating continuously in a single mode is caused by two mechanisms.

One is the external factor which tends to perturbe the cavity for example, temperature fluctuations, vibrations, variations, etc. randomly after the oscillation frequency which results in a finite spectral width. The second more fundamental mechanism which determines the ultimate spectral linewidth of the laser is that due to the ever present random spontaneous emission in the cavity. Since spontaneous emission is completely in coherentwith respect to the existing energy in the cavity mode, it leads to a finite line width of the laser.

In the present paper we have studied the linewidth of five prominent Ar+ laser lines 514.5nm, 501.7nm, 496.5 nm, 488.0 nm and 476.5 nm[1]. In order to obtain a value for the ultimate laser linewidth, we assume that the radiation arising out of spontaneous emission represents a loss as for as coherent output energy is concerned. This loss will them lead to a finite line-width for the laser. The number of spontaneous emission per unit time into mode of cavity is given by $KN_2$ [2]. Where

$$K = (\pi^2 C^3 / \omega^2 n_0^3)\ A_{21} g(\omega) \tag{1}$$

and $N_2$ represents the number of atoms/unit volume in the upper laser level. We are assuming that $N_1 \approx 0$. When the laser oscillates in the steady state then we know

$$N_2 = \frac{n}{n+1} \frac{1}{KT_c} \tag{2}$$

$$\text{That } N2 \approx \frac{1}{KT_c} \tag{3}$$

Where, we are assuming n>>1 and Tc is the passive cavity life time. Thus above threshold, the number of spontaneous emission per unit time will be $KN_2 = \frac{1}{KT_c}$ (4)

Thus the energy appearing per unit time in a mode due to spontaneous emission

$$= h\upsilon_0 / T_c \tag{5}$$

The energy contained in the mode

$$= P_{out}\ T_c \tag{6}$$

The FWHM of spectrum is

$$\Delta\nu_\rho = \frac{\upsilon_0}{Q} \tag{7}$$

The linewidth of the oscillating laser caused by spontaneous emission is given by $\delta\upsilon_{sp}$

Hence the quality factor

$$Q = \omega_o \frac{Energy\ stored\ in\ the\ mode}{Energy\ lost\ per\ unit\ time}$$

Where $\omega_o$ is the oscillating frequency

Thus, We obtain,

$$Q = \frac{\upsilon_0}{\delta\upsilon_{sp}} \tag{9}$$

$$\text{and } Q = 2\pi\nu_0 \frac{P_{out}T_c}{h\upsilon o / T_c} = \frac{2\pi\ P_{out}T_c^2}{h} \tag{10}$$

Now, if $\Delta h_\rho$ is the passive cavity linewidth then

$$T_c = \frac{1}{2\pi\Delta\nu_p} \tag{11}$$

Thus from Eq. (10) we obtain

$$\delta\upsilon_{sp} = 2\pi\ (\Delta\nu_p)^2\ h\nu_0 / P_{out} \tag{12}$$

## 2. METHOD AND RESULTS

The above eq. (12) gives the ultimate linewidth of an oscillating laser and is similar to the one given by Schawlow and Townes. The behavior of these lines have been calculated by applying the formula[3]

$$\Delta\omega_c = \frac{c\delta_c}{2L} \tag{13}$$

$$\text{and } \Delta\omega_L = \frac{\hbar w_0 (\Delta W_c)^2}{2P} \tag{14}$$

i.e., another form of Schawla and Townes formula[4].
Where, $\Delta\omega_c$ is cavity resonance width
$\Delta\omega_L$ is line-width of laser output and $\delta_c = 1 - R_1 R_2$ (15)

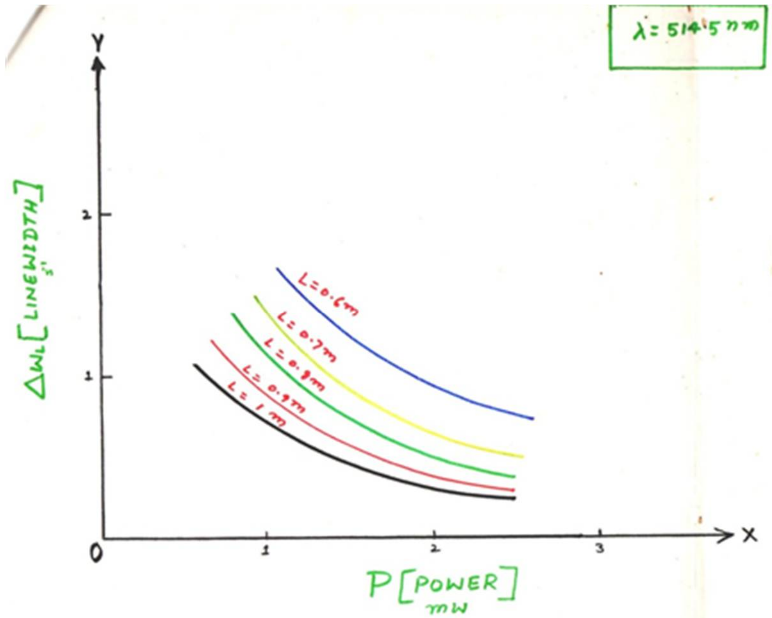


**Figure- 1**

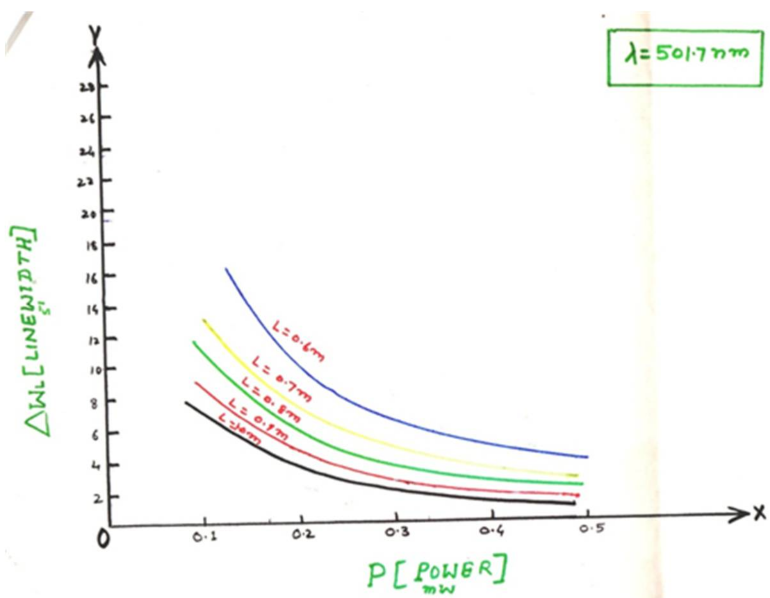


**Figure- 2**

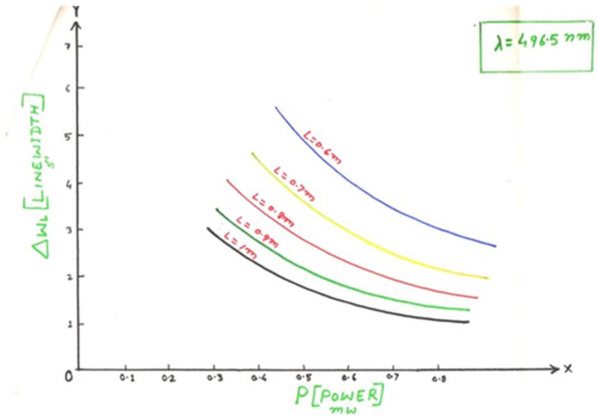


**Figure – 3**

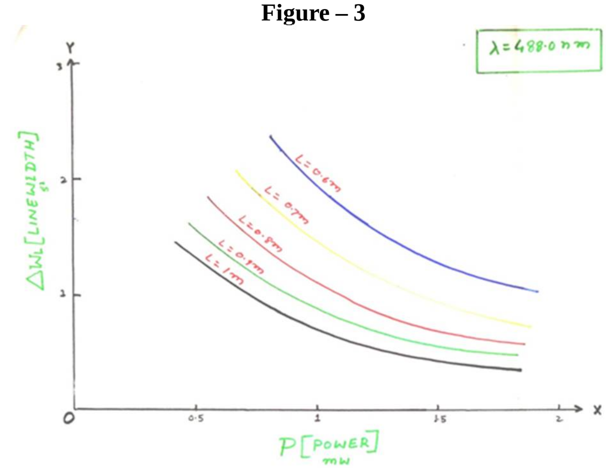


**Figure- 4**

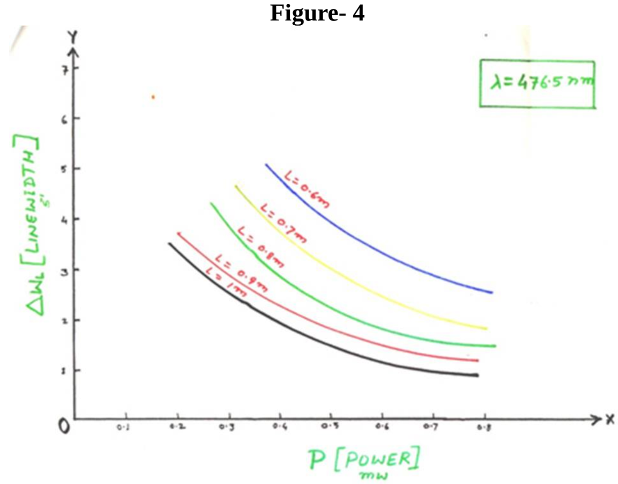


**Figure- 5**

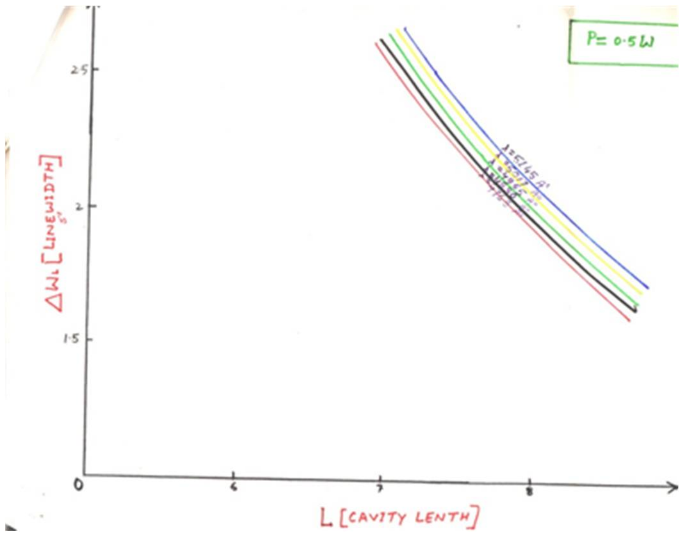


**Figure- 6**

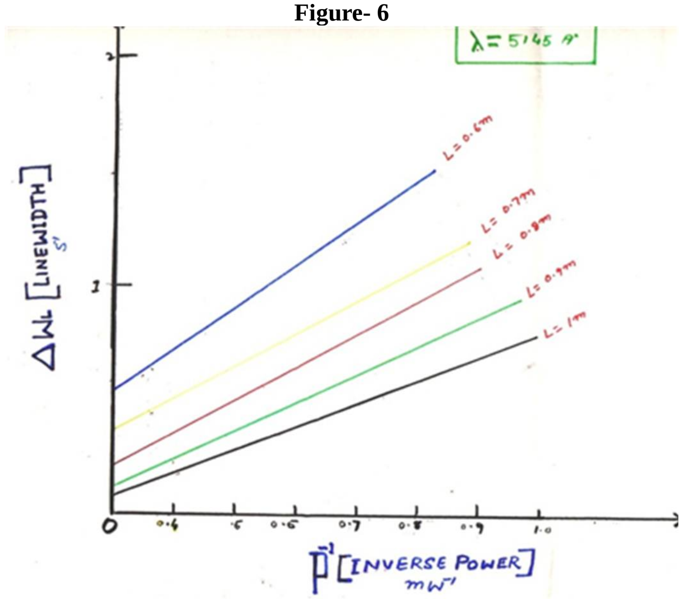


**Figure- 7**

Where, $R_1$ and $R_2$ are the power reflection coefficient of the cavity mirrors at the laser frequency. The graph has been plotted between power[5] and laser linewidth for various cavity lengths varying from 0.6m to 1m for each laser lines. The result have been shown in fig. 1 to 5. Further the graph between linewidth and cavity length has been plotted for different laser lines at a constant output power P= 0.5W, that is shown in fig. 6. The last fig. 7, shows linear increase of line width of single frequency $Ar^+$ laser as a function of reciprocal output power at different cavity lengths.

## 3. CONCLUSION

The similar trend has been found for each laser line, i.e. linewidth is decreasing as the power is increasing. Physically this is due to fact that for a given mirror transmittance, increase in power corresponds to increase in photon number in the cavity, which in turn implies a greater dominance of stimulated transitions over spontaneous transitions. The comparative value of laser linewidth is also decreasing as the length of the cavity is increasing. Hence, we can conclude that lowest laser linewidth the high power and larger length of cavity will be suitable.

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