Spectral density contrast in DPSS and ECD lasers for quantum and other narrow-linewidth applications

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INTRODUCTION

With current endeavours in the UK and around the world to foster the development of new Quantum-based technologies (QT) to sense and detect previously unreachable interactions, such as underground structures and gas leakages, the generation of light sources with highly stabilised output wavelengths have become critical. Diode-pumped solid-state (DPSS) and external cavity diode (ECD) lasers are two of the ideal candidates for narrow-linewidth single-frequency generation. This paper will discuss some of their spectral performance differences.

Current laser technologies are compared upon SWaP-C (size, weight, power & cost) figures.

FUNDAMENTALS

Laser operation is supported for multiple lasing modes with a given cavity geometry and lasing medium. The excitation from the pump source is therefore distributed amongst the supported modes. The first area of interest for narrow-linewidth lasers is therefore mode selection to ensure single longitudinal mode (SLM) operation. In this case, the power in the lasing mode P_0 is proportional to the number of photons associated with the spectral position of that mode. While, the total power is given as the sum of the power stored in the lasing mode, P_0, and the additional spontaneous terms.

The theoretical minimum linewidth or the intrinsic linewidth is given by the Schawlow-Townes limit[1].

$$\Delta f = \frac{v_g^2 h v g n_{sp} \alpha_m (1+\alpha^2)}{8\pi P_0}$$

In this equation Δf is the instantaneous linewidth, whilst α is the detuning term first introduced by Lax[2,3]. The above formula gives an accurate estimate for the linewidth of each system, however Henry[4] showed that for a semiconductor-based system the linewidth can be at least 50-times broader than previously expected. This was explained by the increased spontaneous emission factor, n_{sp}, relevant to semiconductor lasers.

METHODS

In this paper we assessed the spectral performance differences of DPSS and ECD lasers. We showed that due to lower side-mode suppression encountered in ECDLs, less power is coupled in the specified linewidth of the system. We reconstructed some of the most-recently published *narrow-linewidth ECDL* spectra to compare that against one of the best Nd:YAG DPSS lasers in the market. We used the term *spectral density contrast (s.d.c.)* to illustrate the percentage of power emitted within the specified linewidth of the system. In the following analysis we converted the spectral data from a logarithmic into a decimal representation.

$$s.d.c. = \frac{P_{useful}}{P_{measured}} \cdot 100\%$$

RESULTS

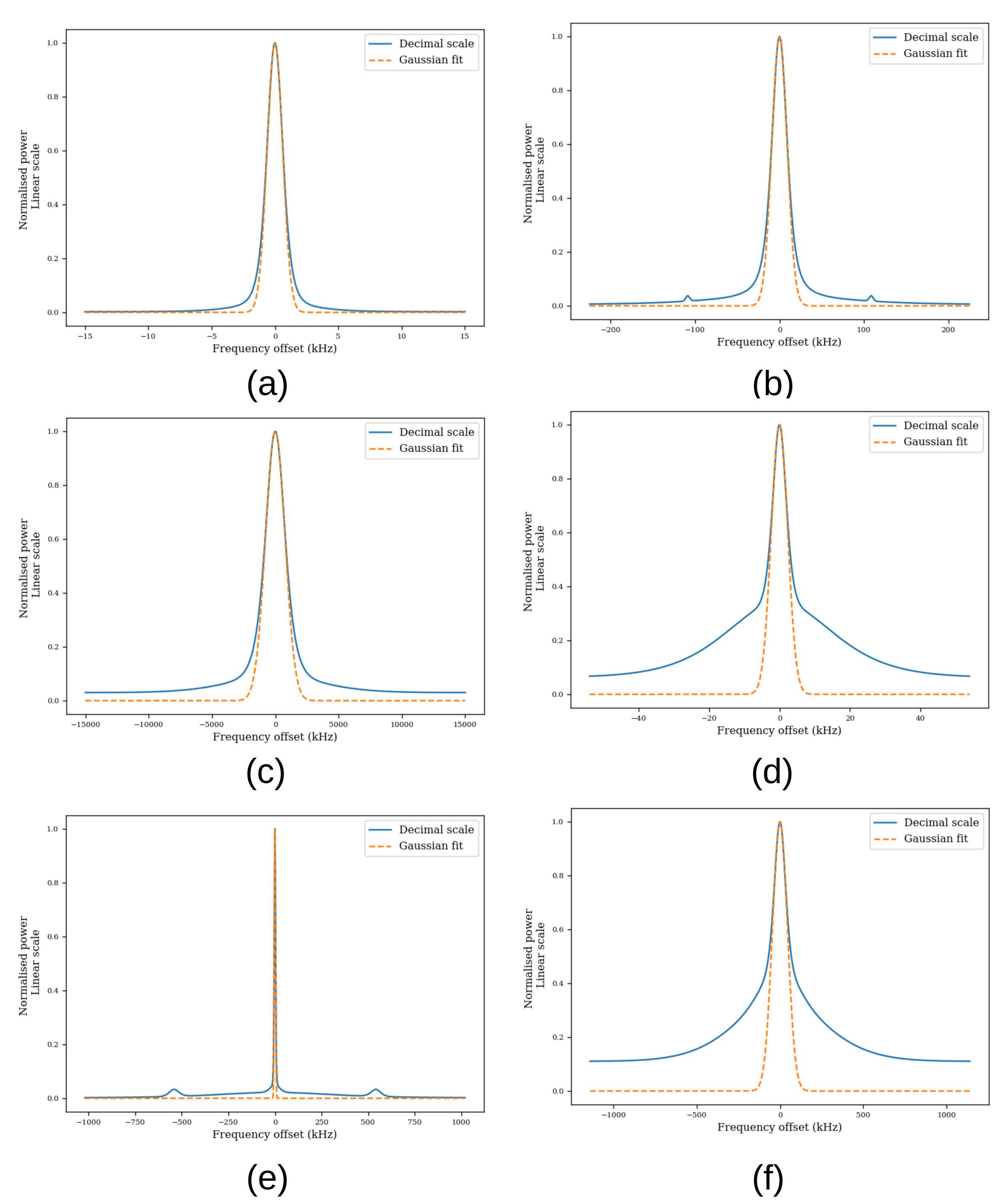
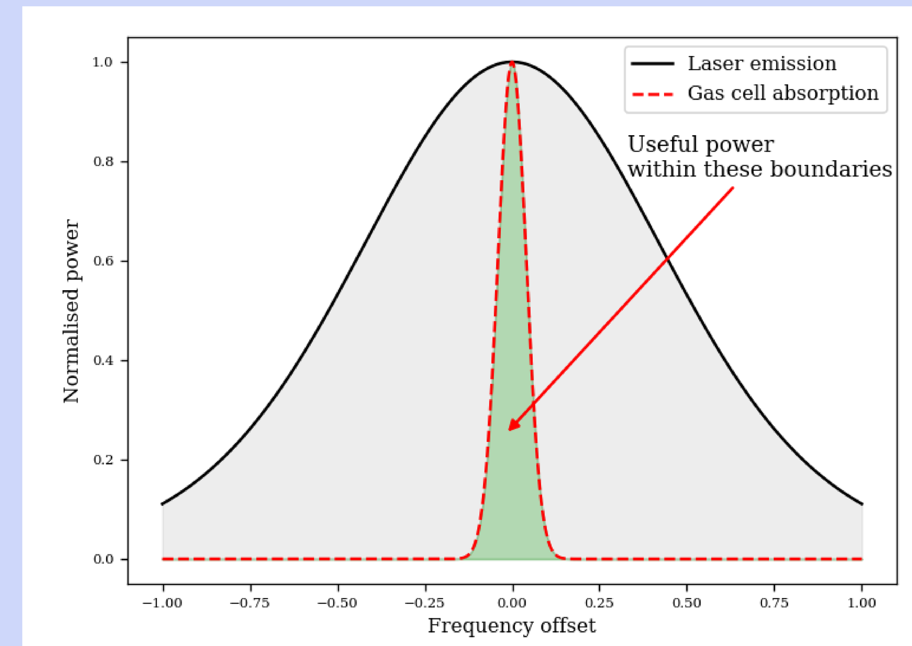


Fig. 1. Illustrating the spectral density contrast estimates for the analysed systems, each subfigure was reconstructed from published data, which was then transformed from a logarithmic to a linear representation. Following captions define *[the source, specified linewidth and s.d.c figure]* of each system. (a) Coherent's Mephisto DPSS laser[5], 1kHz, 80.28%, (b) Kasai et al.[6] 14kHz, 66.34%, (c) Schkolnik et al.[7], 88kHz, 58.54%, (d) Laurain et al.[8],12 4kHz, 27.73%, (e) Bennets et al.[9], 5.2kHz, 24.93%, (f) Zhu et al.[10], 70kHz, 23.24%.

APPLICATIONS

One application for narrow-linewidth lasers is super-high-resolution spectroscopy. Cold atom gas cells are frequently used as absolute-frequency references in these experiments. Absorption broadening is purely defined by the Doppler effect, which results in a Gaussian-shaped absorption line. In the following graph we illustrate the spectral overlap of an arbitrary laser emission curve with the absorption of a gas cell. This shows that the application-specific useful power of the system depends on the lineshape of the laser.



In this respect we can expect a DPSS laser with a *lower* specified output power to perform comparatively to an ECDL with a *higher* output power.

CONCLUSIONS

We showed that due to the dissimilarities in the lineshape broadening between ECD and DPSS lasers, there exists a difference in the spectral density contrast. This consequently indicates that given the same output power specification, the two platforms might provide different levels of useful power. For the examples illustrated in this poster, we found that while an s.d.c. of above 80% can be achieved in the DPSS case, for ECDLs this figure can be as low as 25%, meaning that only a quarter of the emitted power is contained within the specified linewidth of the system. This in turn can have implications on the corresponding SWaP-C figures and the overall feasibility of the two laser platforms.

REFERENCES

1. Schawlow et al., 1958, Physical Review 112
2. Lax, 1967, Physical Review 157
3. Lax, 1967, Physical Review 160
4. Henry, 1982, IEEE Journal of Quant. Electronics 18
5. Coherent Inc. Mephisto data sheet
6. Kasai et al., 2017, Optics Infobase
7. Schkolnik et al., 2018, Laser Physics 29
8. Laurain et al., 2014, Optics Letters 39
9. Bennetts et al., 2014, Optics Letters 22
10. Zhu et al., 2019, Optics Letters 27

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