SOME CHARACTERISTICS OF UNIDIRECTIONAL LASING IN RING LASERS USING THE ACOUSTO-OPTIC EFFECT

W.A. Clarkson, K.I. Martin, D.C. Hanna and A.B. Neilson

Optoelectronics Research Centre

University of Southampton

Southampton, S09 5NH

United Kingdom

Tel. +44 703 593141

Fax +44 703 593142

SUMMARY

For many homogeneously-broadened solid-state lasers, enforcing unidirectional operation of a ring laser can be both a convenient and efficient route to a reliable single frequency output. One attractive way to enforce unidirectional operation, first demonstrated for Ti:sapphire [1] and dye ring lasers [1],[2], is to use a travelling-wave acousto-optic modulator. This technique offers the advantages that it does not rely on polarisation discrimination, unlike the Faraday isolator approach, and requires only one additional intracavity component, so is well suited for use in low-gain, miniature diode-pumped solid-state lasers [3],[4].

Recently, it has be shown that there are two mechanisms which are responsible for the non-reciprocal behaviour of travelling-wave acousto-optic Q-switches. One of these, known as the intrinsic mechanism [5],[6], makes use of the fact that there is a small difference in the Bragg angles for counter-propagating beams and as a consequence they generally experience different diffraction losses. The second mechanism, the feedback

technique [7], is essentially an interferometric technique which makes use of the fact that counter-propagating diffracted beams have different frequencies, since one is upshifted by the acousto-optic frequency and the other downshifed. This approach, although sensitive to length changes, has the particular advantage that a very large loss difference can be achieved with a very low diffraction loss. In either case, the size of the loss difference and the effective insertion loss for the unidirectional device depend on the resonator and acousto-optic modulator designs. In this paper we consider the relative merits of both acousto-optic techniques for enforcing unidirectional operation and suggest a strategy for optimising both resonator and acousto-optic modulator designs in order to enhance the loss difference and minimise the effective insertion loss.

One important feature of miniature ring lasers is that usually one requires only a very small loss difference ($\sim 0.01\%$) to enforce unidirectional lasing. This suggests that laser materials which are not normally noted as having a high enough acousto-optic figure of merit for most acousto-optic applications, may nevertheless prove to have a sufficiently large figure of merit for acousto-optic unidirectional devices. To demonstrate this we have built a resonator (fig.1) which makes use of a Nd-doped phosphate glass acousto-optic modulator as both the laser gain medium and the unidirectional device. The modulator is designed to operate at an r.f. drive frequency of 250MHz and produces only a relatively low diffraction loss of $\sim 1\%$ for an r.f. drive power of 1W. Preliminary results show that unidirectional and single frequency operation can be achieved at r.f. powers as low as ~ 0.008W, which corresponds to a single pass diffraction loss of less than 0.008%. This suggests that many other solid-state laser materials will also prove to have a sufficiently large figure of merit to be used as acousto-optic unidirectional devices.

Whilst enforcing unidirectional operation of a ring laser is a prerequisite for single

frequency lasing it is not necessarily the only requirement. In practice, there are often other small effects which can have a very marked effect on the laser output characteristics and in particular, its frequency spectrum. One such effect, which is commonly ignored, or considered negligible, is spatial hole burning. A small amount of residual spatial hole burning occurs in a unidirectional ring laser due to back reflections from resonator components (e.g. imperfect antireflection coatings) or from other optical components external to the resonator. The amount of spatial hole burning which occurs, and its subsequent effect, depend very largely on the particular ring resonator configuration used. In general, the major effect of residual spatial hole burning will be to limit the maximum single frequency power available from the laser. In order to enhance the single frequency performance it is desirable to adopt a resonator design which completely avoids spatial hole burning. Unfortunately, this is not possible in many miniature laser systems because of the close proximity of the high reflecting mirror to the gain medium. This is especially the case for those resonator configurations in which the dielectric mirrors are coated directly on to the end of the laser rod. One example of such a resonator would be a monolithic resonator (e.g.[8]). In this case spatial hole burning occurs in the region of the gain medium where the incident and reflected beams overlap and, if care is not taken through the appropriate choice of resonator design, can significantly reduce the maximum single frequency power.
In this paper we discuss the effect of residual spatial hole burning in unidirectional ring lasers and present a quantitative model which allows us to predict the maximum single frequency power in any given situation. Using this analysis, we are able to suggest a strategy for the design of single-frequency ring lasers to give improved single frequency performance. In conjunction with the use of the acousto-optic effect in laser materials, for enforcing unidirectional lasing, it should be possible now to design a variety of very compact, efficient

and reliable single frequency lasers with wide range of operating wavelengths.

References

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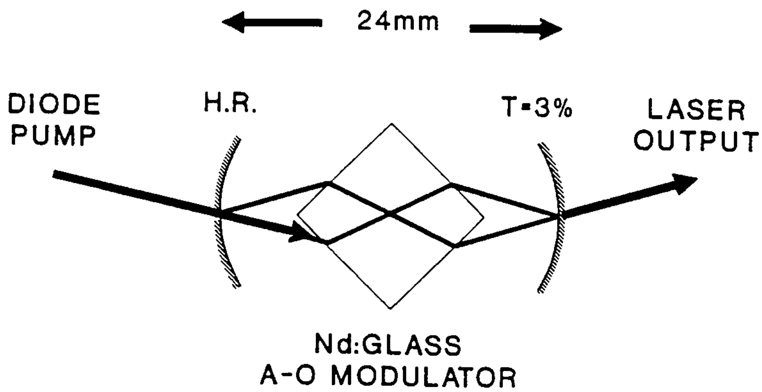

Fig. 1. Diode-pumped Nd-doped phosphate glass ring laser.