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**CMI3 Unidirectional operation of a ring laser by resonating the diffracted beams in a traveling-wave acousto-optic modulator**

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Enforcing unidirectional operation of a ring laser is an attractive way to obtain a single frequency output from a solid-state laser. Recent work[1,2] suggests that a reliable way to achieve unidirectional operation is by using an intracavity traveling-wave acousto-optic (AO) modulator. The nonreciprocal behavior of this device is due to its traveling-wave nature,[3] which causes the counterpropagating beams to suffer different diffraction losses—a consequence of the Bragg condition being satisfied at different angles of incidence for the counterpropagating beams. One important parameter for the device is the ratio of the loss-difference to diffraction loss which can be achieved. For cw operation it is desirable for its value to be as large as possible, to minimize the effective insertion (diffraction) loss in the preferred lasing direction. The value for this ratio depends on a number of factors including details of the *Q*-switch design, its orientation, and the lasing mode dimensions. In practice, it is difficult to obtain values that are much greater than a few tens of percent. For most miniature laser systems this is sufficient, since the loss-difference required for unidirectional operation is usually very small (<0.01%) and hence the insertion loss is negligible. However, for very low gain lasers or multicomponent lasers, which require higher loss-differences, it may be necessary to achieve much higher values for the loss-difference whilst minimizing the insertion loss.

In this paper we describe an alternative technique for enforcing unidirectional operation which involves resonating the first-order diffracted beams in a traveling-wave AO *Q*-switch. Using this approach a much larger value for the loss-difference can be achieved than by using an AO *Q*-switch alone, and in addition the insertion loss can be significantly reduced. The technique involves aligning the *Q*-switch close to the Bragg angle and using a separate ring resonator to feed back and resonate the first-order diffracted beam in the *Q*-switch. For the diffracted beams originating from the two counterpropagation directions, one is upshifted and the other downshifted in frequency by the acoustic frequency. Since their frequencies are different, in general their resonance conditions in the separate resonator are also different. For the diffracted beam which is on resonance, a substantial fraction is frequency-shifted back to the lasing mode frequency and diffracted back into the lasing mode in the original direction and in phase. Thus, this lasing direction is favored since the feedback leads to a net reduction in the diffraction loss. In the ideal case, if the diffracted beam resonator has a negligible round-trip loss, almost all the diffracted beam can be coupled back into the lasing mode. In this way the effective insertion loss for the preferred lasing direction can be made negligible, whereas for the counterpropagating beam, with the corresponding diffracted beam off-resonance, the effective round-trip loss is approximately equal to the diffraction loss. If desired, by adjusting the optical path length in the diffracted beam resonator, by moving a mirror for example, the counterpropagating diffracted beam can be resonated instead and the direction of lasing reversed.

To investigate this technique a number of measurements were made, including a direct measurement of the loss-difference, for a diode-pumped Nd:YAG ring laser. The results show that for low values of diffraction loss (~1%), the loss-difference can indeed approach the diffraction loss, so that for the preferred direction the insertion loss is negligible.

Clearly, this technique for unidirectional operation allows a much larger loss-difference to be achieved than can be obtained by using a traveling-wave AO modulator alone, and offers the advantage over the Faraday isolator approach in that it does not rely on polarization discrimination. We believe that this technique should find use in a variety of low gain miniature ring laser systems.

1. W. A. Clarkson and D. C. Hanna, Opt. Comm. **81**, 375 (1991).
2. W. A. Clarkson and D. C. Hanna, Opt. Comm. **84**, 51 (1991).
3. W. A. Clarkson, A. B. Neilson, and D. C. Hanna, paper submitted to Op. Lett.