Optimization of a TM-mode Amplifying Waveguide Optical Isolator

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An optical isolator that can easily be integrated with its source would significantly decrease the cost of a laser diode module. A promising scheme consists of an amplifying waveguide covered with a magnetized ferromagnetic metal. Earlier, we demonstrated this concept experimentally. Here we report on the optimization of the isolator. Magneto-optic waveguide calculations revealed a subtle interplay between the waveguide dimensions, the cladding material and the properties of the metal film. Our experimental result of 12.7dB optical isolation combined with full compensation of the internal loss is the best ever obtained. With this performance practical implementation is now within reach.

Introduction

An optical isolator is indispensable in a telecom link to protect laser sources against back-reflected light. A waveguide version of this component is highly desirable as it would decrease the packaging cost - hence the overall cost - of a laser diode module largely. An approach that is getting a lot of attention in recent years [1][2] involves the use of a ferromagnetic metal as the source of the non-reciprocal effect. In an optical waveguide covered with a transversely magnetized ferromagnetic metal film close to the guiding region, the magneto-optic (MO) Kerr effect induces a non-reciprocal shift of the complex effective index of the guided mode. Consequently, the modal loss is dependent on the propagation direction of the light. If the guiding core consists of amplifying layers, electrical biasing decreases the internal loss of the waveguide. The result is a device which, being transparent in the forward while providing loss in the opposite direction, is isolating. As the isolator basically has the same structure as the laser it is to be integrated with, monolithic integration is straightforward. This paper discusses the optimization of the TM-mode amplifying waveguide optical isolator.

Simulations

The performance of the amplifying waveguide optical isolator is obviously determined by the magneto-optic strength and the optical absorption of the ferromagnetic metal film and the amount of material gain that can be provided by the amplifying waveguide core. The optimization of both building blocks has been reported earlier [1]. The optimized heterostructure has a tensile strained AlGaInAs multi-quantum well core (9 wells with a thickness of 10nm) and is covered with a 50nm $Co_{50}Fe_{50}$ metal film.

Apart from these main building blocks the refractive index and the thickness of the cladding layers between the guided core and the metal film needs to be properly designed. A rough but very intuitive design rule can be stated like this: as the cladding thickness decreases, both the overall absorption in the metal and the non-reciprocal effect increase due to enhanced overlap of the light with the metal film. However, extensive study of the interaction of the waveguide mode with the metal revealed that the situation is much more complex. The actual non-reciprocal effect is determined by a subtle interplay between the

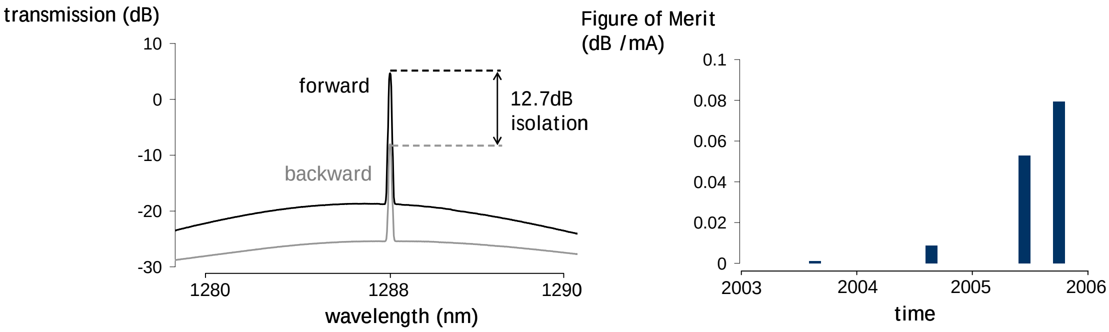

Figure 1: (left) Spectrum of the isolator transmission in both propagation directions, showing 12.7dB optical isolation - (right) Evolution of the demonstrated figure of merit with time.

phase of the (complex) electric field at the metal-semiconductor interface and the phase of the (complex) magneto-optic constants of the metal. It was only after taking this into account that the amplifying waveguide isolator layer structure could really be optimized.

Experimental Results

In figure 1 (left) a measurement example is shown. The transmission of a tunable laser signal through a 2mm long AR-coated isolator is plotted for both propagation directions. The device is electrically pumped with 160mA of current. The difference in transmission between the 'forward' signal and the 'backward' signal equals 12.7dB and the loss in the forward propagation direction is completely compensated (transmission $>$ 0dB). This result is the first demonstration of a transparent optical isolator that can straightforwardly be integrated with a semiconductor laser. In addition, the experimental isolation of 12.7dB is the highest value ever obtained on this kind of device.

Evolution Isolator Performance

Since the first experimental demonstration of the amplifying waveguide isolator mid 2003 [3], the device performance has continuously improved. This is illustrated in figure 1 (right). The suitable figure of merit (FoM) is the optical isolation (in dB) of a device requiring 1mA of current for forward transparency. In the three years that have passed since the first demonstration huge improvement of the FoM by a factor 80 has been achieved.

Conclusion

Improved understanding of the nature of the amplifying waveguide optical isolator resulted in a major advance of the state-of-the-art. We demonstrated the first transparent optical isolator, monolithically integratable with a laser source. The experimental isolation level of 12.7dB shows that practical implementation is now within reach.

References

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