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Monolithic integration of Magneto-Optical Plasmonic Waveguides with GaAs/Al-GaAs Waveguides on GaAs Substrate and with Si Nanowire Waveguides on Si substrate for Integrated Non-reciprocal Optical Devices

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Abstract

The feasibility of integration of a plasmonic optical isolator into a photonic integrated circuits was studied. A method for significant reduction of optical loss of surface plasmons was proposed and experimentally demonstrated.

1. Introduction

The optical isolator is an essential component of optical communication systems. It protects laser diodes and optical amplifiers from unwanted back reflections. In present optical networks a bulk-type optical isolator made of a magnetic garnet is used.

The integration of optical elements into Photonic Integrated Circuits (PIC) is an important task, because it may reduce a cost and improve performance of high-speed optical data processing circuits for the high-speed optical networks. The integration of an optical isolator is important for PIC, because the problem of back-reflected light is more severe in the case of integrated optical elements. However, the optical isolator is one of the few optical components, which has not yet been integrated into commercial OIC. At present, there is a strong industrial demand for the integrated optical isolator.

We are proposing to utilize a surface plasmon in order to fabricate an efficient integrated optical isolator. Advantage of the plasmonic isolator is short length and a good compatibility with the fabrication technology of the PIC.

Till now a long-distance propagation has never been demonstrated for a surface plasmon propagating at an interface of a transition metal, because of high optical loss of the plasmons. The reduction of optical loss of the plasmons is a priority task in order to make a plasmonic isolator suitable for a PIC.

We have showed theoretically [1,2] that it is possible to obtain a low optical loss and a substantial isolation ratio using surface plasmons propagating in a double-dielectric plasmonic waveguide made of a transition metal.

Main result of this work is the experimental demonstration of a significant reduction of optical loss in a plasmonic waveguide using an optimized double-dielectric plasmonic structure. For Fe/SiO2/AlGaAs double-dielectric plasmonic waveguide the low optical loss of 0.03 dB/μm is obtained. As far as we know at present it is a lowest optical loss

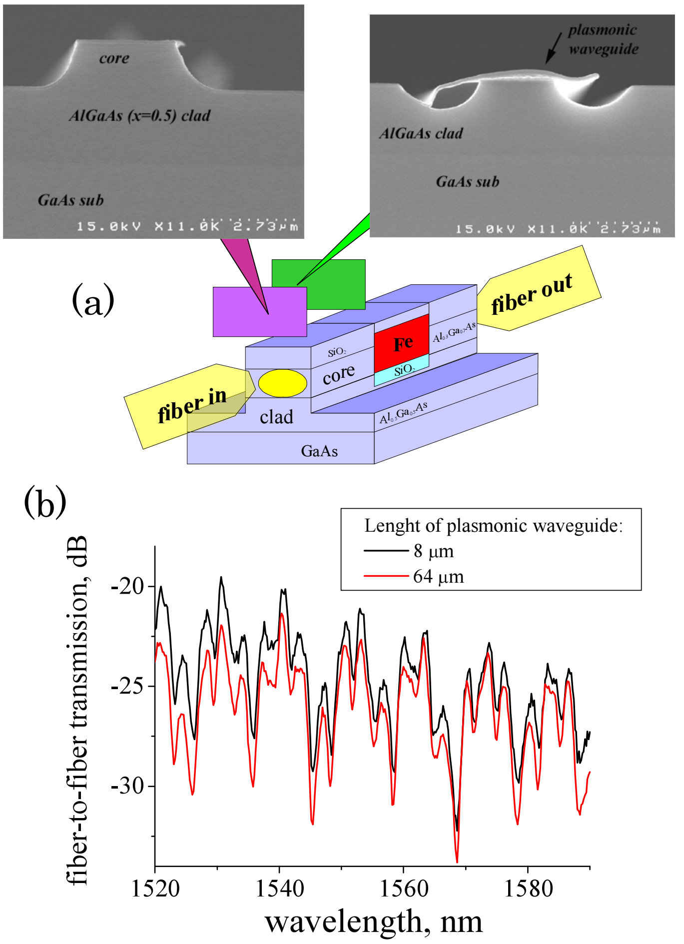

Fig.1. (a) Monolithical integration of an AlGaAs rib waveguide and a Fe/SiO₂/AlGaAs plasmonic waveguide. Cross-sectional SEM images of the AlGaAs waveguide (left) and plasmonic waveguide (right). (b) Measured fiber-to-fiber transmission in cases of a short (8 μm) and long (64 μm) length of the plasmonic waveguide.

demonstrated for a plasmon propagating at a surface of a ferromagnetic metal.

All optical elements in PIC are connected by optical waveguides. A good coupling between the plasmonic isolator and optical waveguides is important for a practical application of the plasmonic isolator. It is known that the distributions of optical field is significantly different in optical and plasmonic waveguides. In optical waveguide, light is confined inside a waveguide core and the distribution is rather symmetric relatively to the waveguide center. In plasmonic waveguide, light is confined in a dielectric at metal/dielectric interface and the distribution is strongly asymmetric. The difference in optical distributions makes difficult to achieve a good coupling efficiency between optical and plasmonic waveguides.

Another achievement of this work is the experimental demonstration of a moderate coupling efficiency of 3 dB per facet between an AlGaAs/GaAs optical waveguide and a Fe/SiO2/AlGaAs plasmonic waveguide.

2. Integrated plasmonic waveguide on a GaAs substrate.

Figure 1 (a) shows a Fe/SiO2/AlGaAs double-dielectric plasmonic waveguide, which was monolithically integrated with an AlGaAs dielectric waveguide. Even though a direct propagation of light from the input to the output fiber is blocked by the iron, light can still pass (See. Fig. 1(b)) by exciting a surface plasmon at the surface of the iron. It was demonstrated experimentally that by utilizing a double-dielectric plasmonic waveguide it is possible to obtain the low optical loss of 0.03 dB/μm for a surface plasmon propagating at the surface of a transition metal (See Fig. 1(b)). It should be noted the oscillations in the transmission spectrum are because of a reflection at AlGaAs-rib-waveguide/ plasmonic-waveguide interfaces.

3. Integration of a plasmonic waveguide with Si nanowire waveguides.

Bending radius of a Si nanowire waveguide can be as small as a few tens of micrometers. It makes the Si nanowire waveguides attractive for a dense integration of optical elements into the PIC. A small size is an important feature of plasmonic devices. The monolithical integration of Si nanowire waveguides with plasmonic waveguide may benefit even a denser integration and new functionalities.

Figure 2 shows a monolithical integration of Si nanowire waveguide (thickness 220 nm, width 450 nm) with Co:SiO2 plasmonic waveguide(width 220 nm). The designs of an isolator utilizing a ring resonator (Fig. 2(c)) or a non-reciprocal coupler are studied. For an efficient coupling between a plasmonic waveguide and Si nanowire waveguide, a side-coupler (Fig. 2(e)) was utilized.

4. Conclusions

Significant reduction of optical loss for surface plasmons propagating at the interface of a transition metal is experimentally demonstrated. For Fe/SiO2/AlGaAs double-dielectric plasmonic waveguide the low optical loss of 0.03 dB/μm is obtained. A moderate coupling efficiency of 3 dB per facet between an AlGaAs/GaAs optical waveguide and a Fe/SiO2/AlGaAs plasmonic waveguide is demonstrated .

This result demonstrates the feasibility of a plasmonic isolator for use in a PIC.

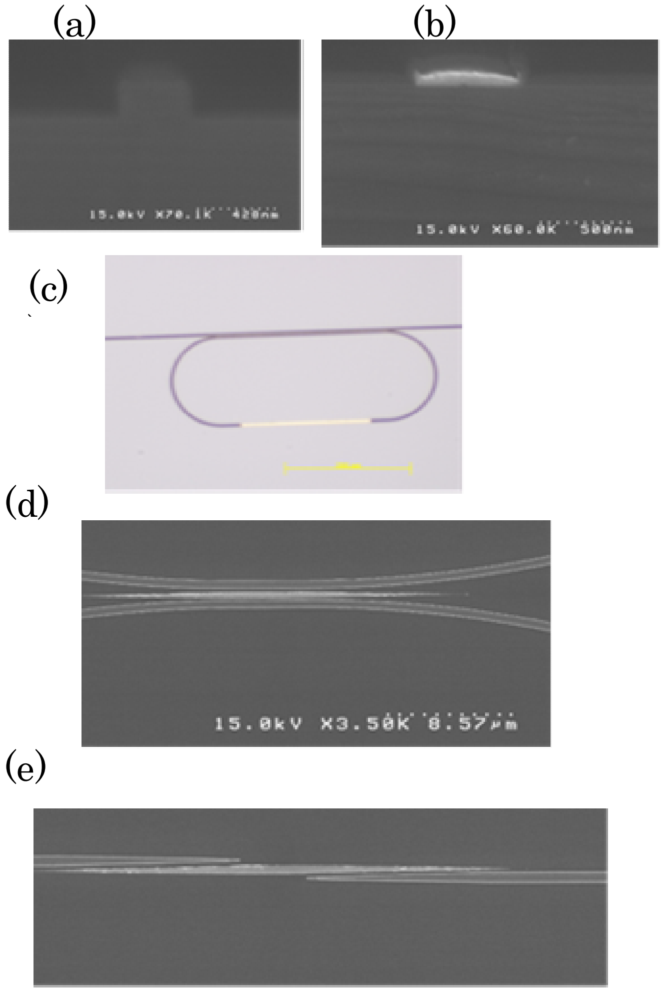

Fig.1. SEM image of monolithically integrated a Si nanowire waveguide and a Co/SiO_2 plasmonic waveguide. Cross-sectional images of (a) a Si nanowire waveguide and (b) plasmonic waveguide. Top-view images of (c) plasmonic waveguide integrated into a ring resonator; (d) non-reciprocal coupler with a 100-nm-wide plasmonic waveguide (e) plasmonic-waveguide/ Si-wire-waveguide side-coupler. In all pictures the plasmonic waveguides are whiter.

References

1] V.Zayets, H.Saito, K.Ando, and S.Yuasa, Materials **5** (2012) 857.
[2] V.Zayets, H.Saito, S.Yuasa, and K.Ando, J. Appl. Phys. **111** (2012) 023103.