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A Design of Optical Isolator Utilizing Surface Plasmons in Co / Al_2O_3 / AlGaAs Waveguides for Integration into Photonic Integrated Circuits

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Abstract

We have theoretically proposed and designed compact optical isolators based on surface plasmon in Co / Al_2O_3 / $Al_{0.5}Ga_{0.5}As$ for photonic integrated circuits. The device shows optical isolation of 0.18 dB / μm and better tolerance of the buffer layer thickness for optical isolation based on surface plasmon.

1. Introduction

Optical isolators are important devices for protecting semiconductor laser diodes (LDs) from unwanted reflected light. Conventional commercially available optical isolators are typically composed of a Faraday rotator and two polarizers. Ferrimagnetic garnets, such as rare-earth iron garnet, are widely used as transparent, passive magneto-optic materials exhibiting Faraday rotation at telecommunication wavelengths. However, Faraday rotators and polarizers are free-space optical devices that are not compatible with III–V based optoelectronic devices. There is a strong demand for semiconductor waveguide optical isolators that can be monolithically integrated with LDs and photonic ICs. Recently, there has also been demand for semiconductor optical isolators that are compatible with silicon waveguides for ultracompact photonic ICs.

III–V- or Si-based semiconductor optical isolators that work on the principle of nonreciprocal loss [1], and surface plasmons [2, 3] have been reported. The feasibility of utilizing of the surface plasmons in a new design of an integrated optical isolator has been studied. It was shown theoretically [2, 3] that it is possible to obtain a low optical loss and a substantial isolation ratio using surface plasmon propagating in a double-dielectric plasmonic waveguide made of a transition metal. Utilizing this plasmonic waveguide, it is feasible to fabricate a competitive plasmonic isolator, which benefits a broad operational bandwidth and a good technological compatibility for the integration into Photonic Integrated Circuits (PIC). In this paper, we report the design of optical isolators utilizing surface plasmons in Co / Al_2O_3 / AlGaAs waveguides.

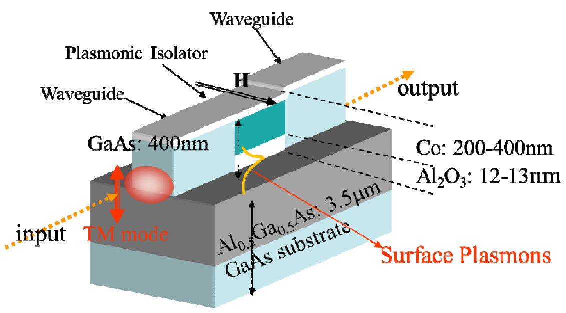

Fig.1 A schematic image of the plasmonic optical isolator utilizing surface plasmons based on Co / Al_2O_3 / $Al_{0.5}Ga_{0.5}As$ for this study.

2. Principle of Plasmonic Optical Isolators and the Device structure

The effective refractive index of waveguides containing transversely magnetized ferromagnetic materials can be changed by the transverse non-reciprocal magneto-optical (MO) effect depending on the magnetization direction. Light experiences the transverse non-reciprocal MO effect only when it propagates in the vicinity of the boundary between the ferromagnetic layer and nonmagnetic layer. The change of effective index by transverse non-reciprocal MO effect is larger when the optical field is evanescent in at least one of the waveguide layers [2]. When light propagates between a ferromagnetic metal and a dielectric in the form of surface plasmons, the optical confinement at the ferromagnetic layer can be changed by the magnetization direction. In case that the optical confinement is near the cutoff in the plasmonic waveguides, a small change of the effective refractive index by magnetization reversal brings significant change of the optical confinement, which leads to substantial non-reciprocal optical loss. The propagation loss of the surface plasmons is strongly dependent on the confinement in the metal surface. Larger optical isolation is expected than that of previously reported semiconductor optical isolator with Fe / InGaAsP / InP [1].

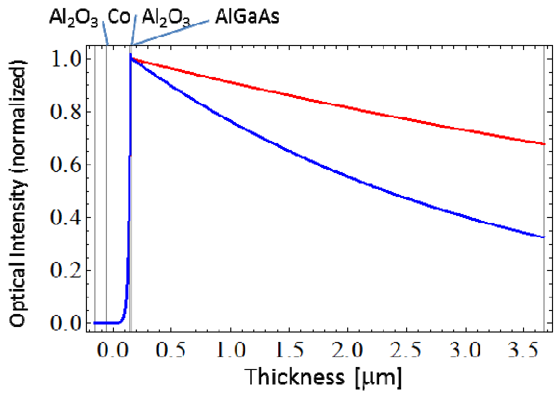

Fig.2 The optical intensity distribution normal to the layer structure for the forward (red curve) and backward (blue curve) propagating light when the thickness of Al_2O_3 layer is 12.5 nm.

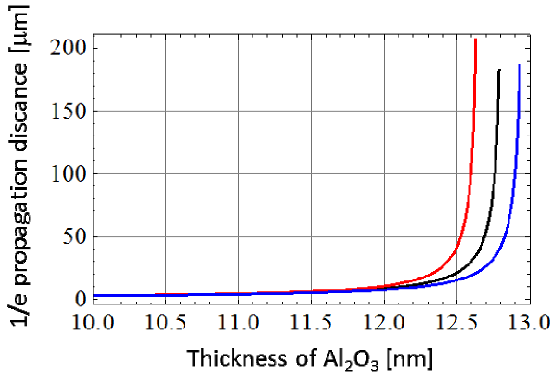

Fig.3 Figure 3 shows the 1/e propagation distance for a surface plasmons propagating in the forward (red curve) and the backward (blue curve) directions (See Fig.1) as the function of the Al_2O_3 layer thickness. The black curve shows the propagation distance without magnetization.

3. Device Structure and Simulations

We have designed the waveguide structure of a plasmonic waveguide in order to realize the cut-off condition and realize optical isolation by surface plasmon. Figure 1 shows the waveguide structure of the plasmonic optical isolator utilizing surface plasmons based on Co / Al_2O_3 / $Al_{0.5}Ga_{0.5}As$ for the transverse-magnetic (TM) mode light with the wavelength of 1550 nm. The plasmonic isolator is set between the input / output waveguides. The refractive indices of Co, Al_2O_3, $Al_{0.5}Ga_{0.5}As$ and GaAs are set at 3.6 + i7.2, 1.746, 3.18, and, 3.37, respectively. The off-diagonal permittivity of Co is set at 1.58 – i2.1. Light is coupled to the surface plasmon at the plasmonic isolator section. When the thickness of Al_2O_3 layer between Co and $Al_{0.5}Ga_{0.5}As$ is 0, light is confined at the boundary between the Co and $Al_{0.5}Ga_{0.5}$ and significant amount of optical field penetrates inside the Co. It causes significant absorption of a surface plasmon. With increasing the thickness of the Al_2O_3 layer, the optical confinement becomes weaker. Eventually, at the cut-off thickness there is no confinement and a surface plasmon cannot propagate. In the case of Al_2O_3 thickness a little thinner than the cutoff thickness, the applied magnetic field can change the confinement of the propagating light and bring a huge optical isolation in a very short plasmonic waveguide, as is schematically shown in Fig. 2. We have calculated the effective index of the plasmonic optical isolators and optical isolation.

4. Simulation Results

Fig. 3 shows the Al_2O_3 layer thickness dependence of the propagation distance for the forward and backward propagating light. In the case when the thickness of Al_2O_3 layer is 12.5 nm, in the forward direction, the 1/e propagation distance is long (41.8 μm), whereas in the backward direction, the 1/e propagation distance is short (only 15.1 μm). This corresponds to the optical isolation of 0.18 dB / μm. In the range of the Al_2O_3 thickness is between 12 and 13 nm, the proposed plasmonic isolator provides a substantial isolation above 0.17 dB / μm. The proposed design of the isolator made of Al_2O_3 / Co structure has an advantage comparing previously studied design made of the SiO_2 / Co. The refractive index of Al_2O_3 is larger than that of SiO_2 in the Co / SiO_2 / AlGaAs plasmonic isolator, the thickness range (1 nm) for the optical isolation by surface plasmon is a little larger than that with SiO_2 buffer layer (0.5 nm) [2, 3]. Therefore the required oxide thickness is thicker and technologically easier to fabricate it.

5. Conclusions

We have proposed and designed plasmonic optical isolator utilizing surface plasmons based on Co / Al_2O_3 / $Al_{0.5}Ga_{0.5}As$. The device shows optical isolation of 0.18 dB / μm and better tolerance for precision of the buffer layer (Al_2O_3) thickness, which is promising for ultra-compact optical isolators for photonic integrated circuits.

References

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