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Surface Plasmon Enhanced Magneto-Optic Isolator

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Abstract: Here we present an integrated isolator design based on nonreciprocal coupling into a magneto-optic surface-plasmon waveguide that achieves an isolation $> 30\text{dB}$ with an insertion $< 3\text{dB}$ in a device length $< 100\mu\text{m}$.

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Magneto-optic surface-plasmon devices show promise for integrated photonic applications. Photonic devices such as isolators, modulators, and photonic switches could benefit from magneto-optic plasmonics. Nonreciprocal phase shift isolators have been proposed using surface-plasmon magneto-optic slab waveguides [1,2]. The insertion loss in these devices is limited by the plasmon propagation loss. Here we present an isolator design which exploits the surface-plasmon loss to achieve large isolation.

The coupling between modes in two adjacent waveguides is well described by coupled-mode theory. In Figure 1a we consider the coupling between two waveguides consisting of the dielectric waveguide (WG1) and the surface plasmon waveguide (WG2). Individually, the waveguides are described by propagation constants β_1 and β_2 for the dielectric and surface plasmon waveguide respectively. When the two waveguides are brought together they interact leading to a coupled mode solution for the total waveguide shown in Figure 1b. The coupling strength between the two waveguides depends on their relative separation and the matching of their effective indices. In Figure 1 the surface-plasmon metal consists of a 100nm thick iron film of length $< 100\mu\text{m}$. An external magnetic field is applied in a direction transverse to the beam propagation.

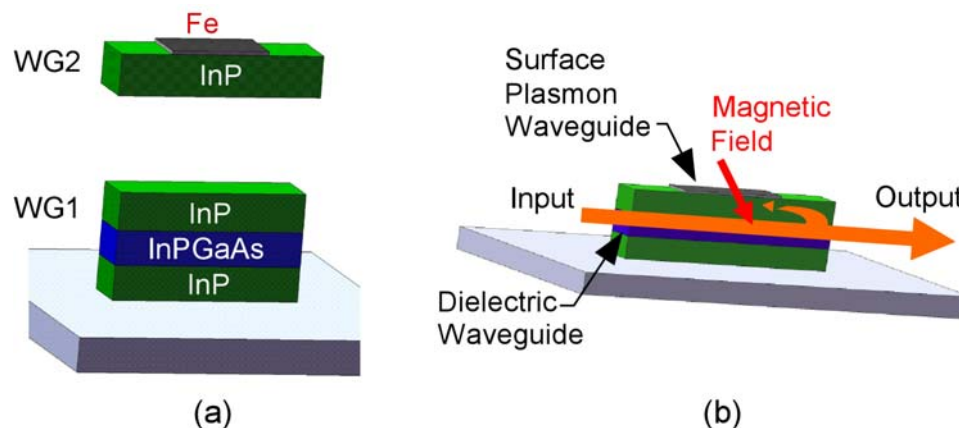


Fig. 1. (a) Two waveguides used in coupled mode theory. (b) Nonreciprocal coupling between the two waveguides for use as an isolator.

The magnetic field induced nonreciprocity of the surface plasmon waveguide results in a different effective index in the forward and reverse directions denoted by $n_{eff,sp,fwd}$ and $n_{eff,sp,rvs}$ respectively. For efficient coupling to occur in the reverse direction the real part of the effective index must match the effective index of the dielectric waveguide $n_{eff,d}$ [3,4]. In the forward direction, the two indices must be sufficiently mismatched ($n_{eff,d} \neq n_{eff,sp,fwd}$) for weak coupling to result allowing for a low insertion loss. Figure 2 illustrates the nonreciprocal behavior of the surface plasmon mode as a function of the iron film thickness with an applied saturated magnetic field in the transverse direction of propagation (Voigt geometry).

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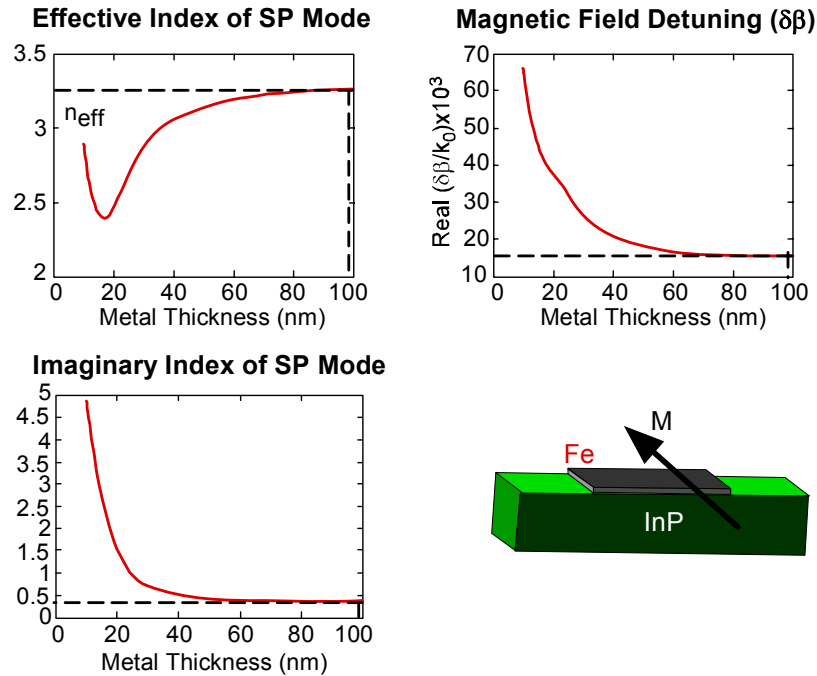


Fig. 2. Magneto-optic properties of an iron film surface plasmon waveguide.

As shown in Figure 2, the effective index of the surface plasmon mode in the reverse direction can be matched to the effective index of the dielectric waveguide by varying the metal thickness. For a 100nm thickness, the effective index of the surface plasmon mode matches the effective index of the dielectric mode ($n_{eff,sp,rvs}=n_{eff,d}=3.25$). We define a detuning parameter ($\delta\beta/k_0 = n_{eff,sp,fwd} - n_{eff,sp,rvs}$) which results from applying a saturating magnetic field to the surface-plasmon magneto-optic metal. By appropriately choosing the upper cladding thickness which separates the dielectric waveguide and the surface-plasmon waveguide device lengths smaller than $100\mu\text{m}$ are achievable. The imaginary index of the surface-plasmon mode is also illustrated in Figure 2. The imaginary index illustrates that the surface plasmon mode undergoes rapid attenuation with a $1/e$ extinction length of $5.7\mu\text{m}$ providing greater than 30dB isolation in device lengths less than $100\mu\text{m}$.

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