Loss compensation in long-range dielectric loaded surface plasmon polariton waveguides

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Abstract-Loss compensation in long-range dielectric loaded surface plasmon polariton (LR-DLSPP) waveguides has been theoretically studied. Rare-earth-ion-doped potassium double tungstates have been proposed as gain materials because of the elevated gain that they can provide, together with a favorable refractive index. The effect of the waveguide geometry on loss compensation efficiency was thoroughly studied. A material gain as low as 12.5 dB/cm was found to suffice to achieve full loss compensation in an optimized structure.

Loss compensation and amplification in plasmonic waveguides has been the subject of great deal of research in recent years [1-5]. The significant propagation loss of plasmonic devices has hindered their wide-spread use in many interesting applications, such as on-chip optical circuitry, optical interconnects and optical biosensors, which benefit from the potential ultra-compactness, high speed and efficient delivery of active control signals enabled by the presence of the metal amidst the optical mode. In this work, we propose the integration of rare-earth-ion-doped potassium double tungstate gain materials into a long-range dielectric loaded surface plasmon polariton (LR-DLSPP) waveguide structure. Rare-earth-ion-doped materials can provide stable optical gain suitable to amplify data rates of > 1 Tbps. A high gain (~1000 dB/cm) has recently been demonstrated in an ytterbium-doped waveguide amplifier at a wavelength of 980 nm [6]. Furthermore, these materials present a refractive index of n ~ 2.05 that closely matches that of silicon nitride, therefore permitting the design of low-loss LR-DLSPP waveguides.

A LR-DLSPP waveguide consists of a low-refractive-index substrate, a buffer layer with a higher refractive index than the substrate, a metal stripe and a ridge of a material with refractive index similar to the buffer layer [7]. In order to minimize propagation losses, the electric field above and below the metal stripe should be as balanced as possible. This is achieved by optimizing the dimensions and refractive indices both above and below the metal stripe. Figure 1 shows two of such LR-DLSPP waveguide structures incorporating a rare-earth-ion-doped potassium double tungstate as gain material [8]. In Structure 1, Fig. 1(a), the gain material is introduced as the buffer layer, while in Structure 2, Fig. 1(b), the gain material is introduced as the ridge. The effect of the waveguide geometry on the efficiency of loss compensation by the gain material is analyzed by finite-difference simulations using the PhoeniX Software.

A minimum material gain of 37 dB/cm is required for Structure 1 (ridge dimensions $1.6 \times 1.6\ \mu m^2$ and buffer thickness 0.37 μm). A gain as small as 12.5 dB/cm suffices to fully compensate propagation losses in Structure 2 (ridge dimensions $0.8 \times 0.8\ \mu m^2$ and buffer thickness 0.35 μm). This latter structure supports a propagation mode with sub-micron lateral dimension (0.92 μm).

In this paper, the details of the theoretical simulations will be presented, as well as preliminary experimental results on the fabrication of such structures.

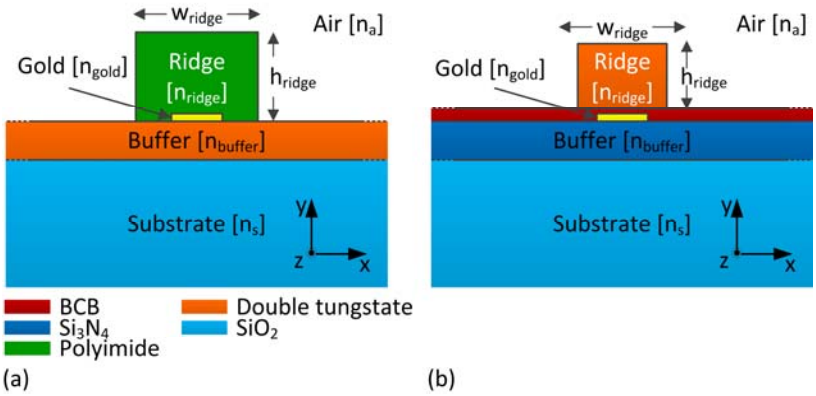

Fig. 1. Layout of the LR-DLSPP structures with gain analyzed in this work. (a) Structure 1: Gain material in the buffer and polyimide ridge; (b) Structure 2: Gain material in the ridge, buffer layer in silicon nitride and 100-nm-thin BCB adhesive layer between buffer and ridge.

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