Gain Assisted Long Range Surface Plasmon Using Multiple Quantum Wells

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Abstract: We propose a structure that compensates surface plasmon (SP) losses using quantum well (QW) gain medium. A finite height superstrate is used to achieve significant reduction in gain requirement for lossless SP propagation.

OCIS codes: (240.6680) Surface Plasmon; (250.5980) Semiconductor optical amplifiers

Introduction

The use of surface plasmons (SPs) offers the possibility of many new devices and the potential to bridge the gap between electronics and photonics. The biggest obstacle for realizing “plasmonic” devices is the high attenuation of the SPs. Nezhad et al. have proposed the use of a medium with optical gain to compensate these losses [1]. We propose a new structure consisting of multiple quantum wells adjacent to a finite width metallic stripe to achieve the necessary loss compensation. We analyze the amount of the gain needed and show that the required gain is attainable using the current state of the technology. The effects of the superstrate thickness and its optical parameters are considered and it is shown that they can be used to further reduce the SP losses, hence reducing the amount of the required gain from the QWs

The Proposed Structure

Fig. 1 shows the proposed structure. A metal stripe is placed on a multiple QW structure. The gain medium consists of five QW layers, each 10 nm thick and separated from each other by a 20 nm thick barrier. The compositions of the QW and the barrier layers are $Al_{0.12}Ga_{0.12}In_{0.76}As$ and $Al_{0.3}Ga_{0.18}In_{0.52}As$, respectively. To reduce the loss due to free carrier absorption, the top QW is separated from the metal film by a 50 nm buffer layer. The entire structure is supported by a semi-infinite InP substrate. The dielectric constants for the well and barrier layers are 12.2 and 11.2, respectively. These values are typical for AlGaInAs QWs at 1.55 µm wavelength. The superstrate dielectric constant is matched to that of the barrier layers. The dielectric constant of silver at 1.55 µm wavelength is -116.38+ i 11.1 [2] and the losses in InP substrate and the QW barriers are assumed to be negligible.

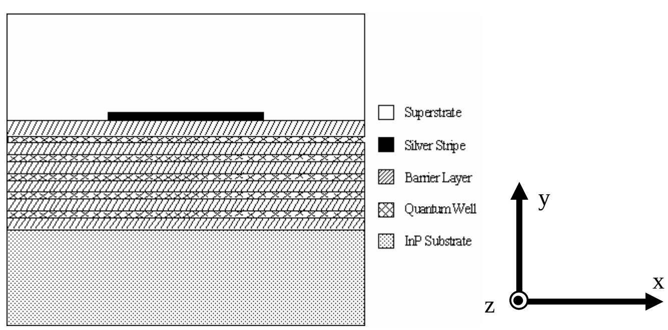
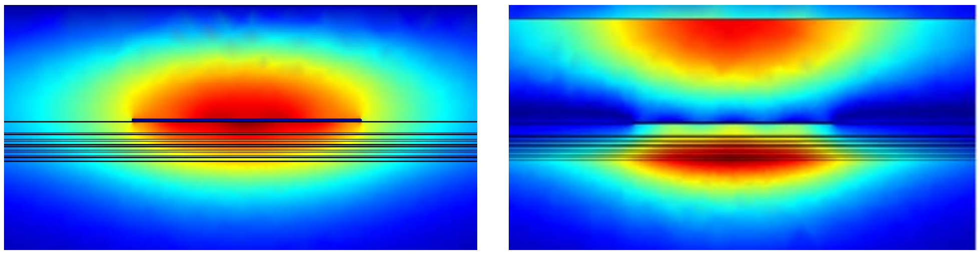


Fig. 1: Proposed structure for gain assisted lossless SP

Analysis and results

The commercial finite element code FEMLAB is used for the analysis. Finite superstrate height is found to significantly alter the SP characteristics. If a semi-infinite superstrate is assumed in Fig. 1, for a 1 µm wide metallic stripe, the long range SP cut off occurs for a metal thickness of 25 nm or less. On the other hand, when the superstrate has finite height, the long range SP exists for much thinner films. This makes it possible to have much lower attenuation of the plasmon mode and to reduce the gain required from the QWs. Moreover, it is noted that for a very thin metallic film the mode profile changes. As an example E_y

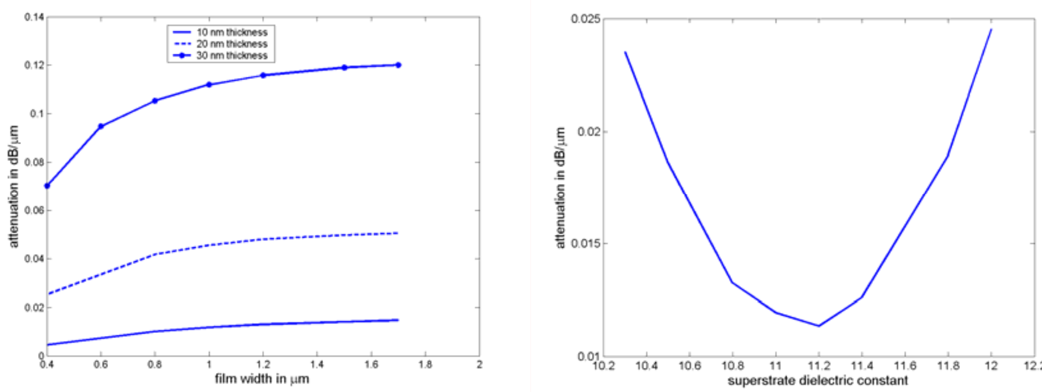
and E_z field components for a 1 μm wide and 10 nm thick stripe are shown in Figure 2. E_z component is different than that of a conventional SP mode [3]. However, the two field components responsible for power flow, i.e., H_x (not shown here) and E_y remain similar to the SP mode and therefore power is still well guided by the stripe. This mode is still a SP mode. The gain requirement for lossless SP propagation in this case is 406 cm^{-1}; a value easily attainable from QW structures [4].



(a) (b)

Fig. 2. Field profiles for a 1 μm wide and 10 nm thick silver stripe (a) E_y (b) E_z

Parametric studies have been carried in order to assess the effects of the metal thickness and width and the superstrate dielectric constant and loss on the attenuation of SP mode and its overlap with the QW layers. Some of the important results are shown in Fig. 3. The attenuation decreases with reduced strip width and thickness as shown in Fig. 3(a). However, an extremely narrow and thin metallic film loses the ability to guide the SP. It is found that superstrate dielectric constant should be matched to the barrier layers to minimize the loss. The optimum dimension of the metal film depends on different parameters such as losses in the surrounding media and available gain from the QWs. This optimization will be discussed during the presentation.



(a) (b)

Fig. 3. Variation of SP attenuation with (a) stripe width and thickness (b) superstrate dielectric constant.

In conclusion the proposed structure is capable of achieving lossless propagation of SPs. We observe that a finite thickness superstrate results in drastic modification of the SP field.

References

[1] M.P. Nezhad, K. Tetz, Y. Fainman, "Gain assisted propagation of surface plasmon polaritrons on planar metallic waveguides", Optics Express, 12(17), 4072- 4079, (2004).

[2] E. D. Palik, "Handbook of optical constants of solids", (Academic Press, Inc, 1985).

[3] P. Berini, "Plasmon polaritron waves guided by thin lossy metal films of finite width: Bound modes of asymmetric structures", Phys. Rev. B, 63, 125417.

[4] S. Y. Hu, D. B. Young, S. W. Corzine, A. C. Gossard, L. A. Coldren, "High-efficiency and low-threshold InGaAs/AlGaAs quantum well lasers", J. Of Appl. Physics 76, 3932-3934, (1994).