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Design of Wavelength Demultiplexer with grating using Arrayed Plasmonic Cavities

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Abstract— *A structure based on the metal insulator metal plasmonic cavities with grating in the bus waveguide for wavelength demultiplexing is designed and numerically investigated by finite difference time domain (FDTD) method. In this demultiplexing structure plasmonic slot cavities are perpendicularly coupled with the bus and drop waveguides. In this demultiplexer wavelengths of each channel depends on length of the plasmonic slot cavity and width of the transmission band can be adjusted by changing the coupling distance between plasmonic slot cavity and bus/drop waveguide. By the use of terminated bus waveguide maximum transmission efficiency increased up to 70% which is nearly up to two times higher than the result obtained by the without terminated bus waveguide. By the use of grating in the proposed structure of demultiplexer the transmission efficiency increases very well as compare to previous proposed designs. This proposed structure with grating in the bus waveguide could be utilized to develop ultra compact optical wavelength demultiplexing device for large scale photonic structure especially in WDM systems in nanoscale.*

Keywords—FDTM, Demultiplexer, Plasmonic Cavities, WDM.

I. INTRODUCTION

Plasmonic circuits are able to combine the superior advantages of photonics and electronics on the same chip because these circuits can carry optical signals and electric currents through the same thin metal circuitry. Plasmons are the collective oscillation of free electron gas density at optical frequencies. Plasmon can couple with a photon to create another quasi particle called plasmon polaritons. Surface Plasmon Polaritons are infrared or visible frequency electromagnetic wave trapped at or guided along metal dielectric interfaces. SPPs overcome the diffraction limit of light in optics due to subwavelength mode confinement in plasmonic waveguides. Plasmonic waveguide, e.g. metal insulator metal has good application in nano plasmonic integrated circuits due to its subwavelength mode confinement capability and control the light in nanoscale configuration.

Wavelength selecting and demultiplexing is very important phenomena in optical communication. In wavelength demultiplexer we can demultiplex or separately select the several wavelengths in different channels. Reflected or selected waves in this structure are in same channel, not easy to separate these wavelengths. Plasmonic demultiplexer is designed with three rejective or selective filters to drop three wavelengths, received in three output branches.

In this paper three channel wavelength demultiplexer based on plasmonic cavities with terminated bus waveguide and grating in the bus waveguide which are perpendicularly coupled with the bus and drop waveguideis proposed and numerically analyzed by Finite Difference Time Domain (FDTD) method. In this demultiplexer wavelengths of each channel depends on length of the plasmonic cavity and width of the transmission band can be attuned by changing the coupling distance between plasmonic cavity and bus/drop waveguide.Single band transmission in each channel can be achieved by selecting the proper position of the drop waveguide.By the use of terminated bus waveguide transmission efficiency increased up to 70% which is nearly up to two times higher than the result obtained by the without terminated bus waveguide. It is because the bus waveguide end can reflect the transmitted power, and thus large amount of power is coupled into the slot cavities by the evanescent coupling. By the use of grating the transmission efficiency increases very well as compare to previous designs. Due to grating in the bus waveguide more surface plasmons are generated and more coupling of SPPs will be done in the slot cavity so the amplitude of transmission peak becomes increases.

II. WDM STRUCTURING

Figure 1 shows three channel wavelength demuliplexing structure with terminated bus waveguide and grating in the bus waveguide, which is simply composed by three plasmonic slot cavities which are perpendicularly coupled with the bus and drop waveguides. The material used in the

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wafer is silver and in slot cavities and in the bus/drop waveguide is air (ε_d=1).The width of the bus/drop waveguides and the cavity are same and fixed as w =w_t = 50nm.The length L_1, L_2, L_3 of the plasmonic slot cavities are 270 nm, 390 nm and 470 nm. Since the width of the MIM waveguide is very less as compare to incident wavelength, whose dispersion relation is given by the following equation:

$$\varepsilon_d k_m + \varepsilon_m k_d \tanh\left(\frac{k_d}{2}\omega\right) = 0$$

where k_d and k_m are defined as $k_d = (\beta^2-\varepsilon_d k_0^2)^{1/2}$ and $k_m= (\beta^2-\varepsilon_m k_0^2)^{1/2}$, ε_d and ε_m are respectively dielectric constants of the insulator and the metal and k_0=2π/λ is the free space wave vector. The effective refractive index of the MIM waveguide is n_{eff}= β/k_0.

The frequency dependent complex relative permittivity of metal ε_m (ω) can be characterized by the drude model:

$$\varepsilon_m (\omega) = \varepsilon_\infty - \omega_p^2/\omega (\omega+i\gamma)$$

where ε_∞ is the dielectric constant at the infinite frequency, and γ and ω_p are the electron collision frequency and the bulk plasmon frequency respectively. ω is the angular frequency of incident light. The parameters for silver can be set as ε_∞=3.7, ω_p=9.1eV, γ=0.018 eV. TM Polarized incoming pulse is generated at the left end of the bus waveguide and discrete Fourier transform is used to obtain the spectral response of the designed structure. The evanescent coupling is used in the wavelength demultiplexing structure to couple the light at the resonance wavelength into the slot cavities.

III. REALIZATION of WAVELENGTH FILTERING CAPABILITY inTHE DEMULTIPLEXER

When the SPP's wave propagates along the bus waveguide, the light at the resonance wavelength can be effectively coupled into the slot cavity via the evanescent coupling and form the standing waves in the cavity and partly coupled in the drop waveguides. Defining Δϕ is the total phase delay of the SPP's waves propagating per round trip inside the slot cavity, Δϕ = 4πn_{eff}L/ λ + ϕ_r, where ϕ_r = ϕ_1+ ϕ_2, ϕ_1 and ϕ_2 are the additional phase shift of a beam reflected on the upper and lower facets of the slot cavity respectively, L is the length of the slot cavity.

The resonance wavelength can be obtained only when the following resonance condition is satisfied: Δϕ = m*2π, m is the order of the resonance mode. So the resonance wavelength λ_m can be expressed as follows:

$$\lambda_m = \frac{2n_{eff}L}{(m-\phi_r/\pi)}$$

where n_{eff} is the real part of the effective index in the resonant cavity and λ_m is the vacuum wavelength of the waves. Resonance wavelength is linear to the effective index and length of the cavity. Only the waves that satisfy the resonance wavelength condition can be formed as standing waves in the slot cavity, and coupled into the drop waveguide to be selected.

In this paper a new design of wavelength demultiplexer is proposed with terminated bus waveguide and grating in the bus waveguide. Grating width is .02 µm, length is .01 µm and distance between two adjacent gratings is .01 µm. The mismatch in wave vector between the in-plane momentum k_x = k sin θ of impinging photons and β can also be overcome by patterning the metal surface with a shallow grating of grooves or holes with lattice constant a. The Phase matching takes place whenever the condition

$$\beta = k\sin\theta \pm \nu g$$

is satisfied, where g=2π/a is the reciprocal vector of the grating and ν = (1, 2, 3 . . .). SPPs propagating along a surface modulated with a grating can couple to light and thus radiate.

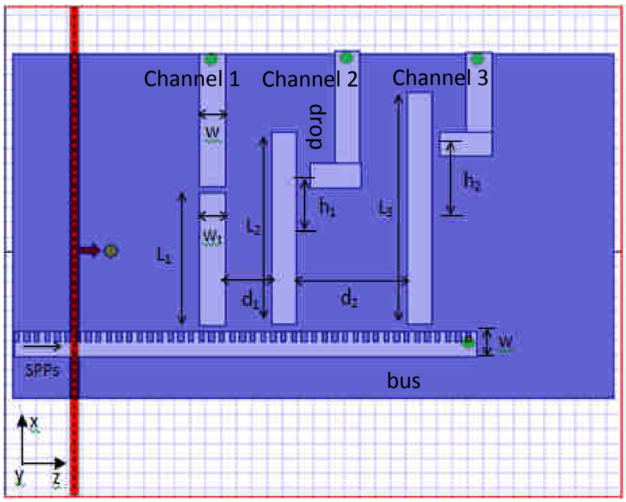

Fig. 1 Schematics of Improve wavelength demultiplexing structure based on arrayed plasmonic slot cavities (with grating in the bus waveguide) with d_1= 150 nm, d_2 = 213 nm, and h_1 =106 nm, h_2 =132 nm.

By the use of grating the transmission peak amplitude becomes two times higher as compare to previous designs. Due to grating in the bus waveguide more surface plasmons are generated and more coupling of SPPs will be done in the slot cavity so the amplitude of transmission peak becomes increases.

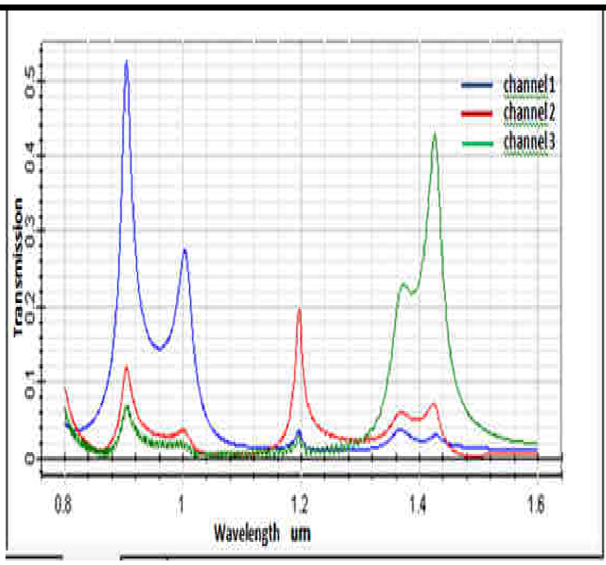

Fig. 2 Transmission spectra of three channels Improve wavelength demultiplexing structure with three plasmonic slot cavities (with grating in the bus waveguide)

Table I
DEMULTIPLEXED WAVELENGTH and TRANSMISSION PEAK AMPLITUDE forIMPROVE WAVELENGTH DEMULTIPLEXING STRUCTURE BASED onARRAYED PLASMONIC SLOT CAVITIES (withGRATING intheBUS WAVEGUIDE).

Channel No.	Center Wavelength of GMCW Pulse (μm)	Demultiplexed wavelength (μm)	Normalized Amplitude
1.	1.55	0.92	0.53
2.	1.55	1.19	0.21
3.	1.55	1.43	0.43

As compare to previous proposed designs the transmission peak of proposed design in this paper maximum transmittance has increased up to 80% which is nearly up to two times higher than the result obtained by the without terminated bus waveguide.

IV. CONCLUSIONS

The work in the paper is concerned about the design of wavelength demultiplexer with terminated bus and grating in the bus waveguide to demultiplex or separately select the several wavelengths in different channels. Wavelength selecting and demultiplexing is very important phenomena in optical communication. The design of wavelength demultiplexer is based on arrayed plasmonic slot cavities which are perpendicularly coupled with the bus and drop waveguides. The width of the MIM waveguide is much smaller than the incident wavelength of light, so this wavelength demultiplexer uses the nanometer scale confinement. Due to the nanometer-scale Confinement, Surface Plasmon based wavelength demultiplexer is very useful for realizing the optical nano-Circuitry.

By the use of terminated bus waveguide maximum transmittance has increased up to 70% which is nearly up to two times higher than the result obtained by the without terminated bus waveguide. It is because the bus waveguide end can reflect the transmitted power, and thus more power is coupled into the slot cavities by the evanescent coupling. By the use of grating the transmission efficiency increases very well as compare to previous designs. Due to grating in the bus waveguide more surface plasmons are generated and more coupling of SPPs will be done in the slot cavity so the amplitude of transmission peak becomes increases. The new design of wavelength demultiplexer increases the transmission peak amplitude. So this wavelength demultiplexing structure is very useful in all integrated circuits for optical computing and communication, especially in WDM systems in nanoscale.

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