Chapter 6

Conclusion and future scope

Contents

6.1 Conclusion

As discussed, integrated optical processors are indispensable for high speed optical communication and instruments. In this direction, there is a need for compact components for large scale integration. Two-mode interference coupler is an ultra-compact device component of integrated optical devices. Our works are mainly based on two-mode interference coupler using surface plasmonic waveguides.

Firstly, we have reviewed the previous works on planar optical waveguide components such as directional coupler, multimode interference coupler and two-mode interference coupler and their theoretical backgrounds. It is seen that two-mode interference waveguide structure is simpler and more compact than other structures. We have also mentioned previous works on SPP waveguides used for integrated optical processors and related theory. The KCl:Tl^0(1) pulsed laser has been discussed for optical control of these SPP waveguides.

An ultra-compact surface plasmonic two-mode interference (SPTMI) waveguide has been introduced as a basic component for integrated optical processor devices. The proposed structure consists of silicon core, silver upper and lower cladding and GaAsInP left and right cladding. The refractive index of GaAsInP shows a nonlinear refractive index change on application of optical pulse energy. By modulating the refractive index of GaAsInP cladding with incidence of optical pulse, an additional phase change can be introduced between the excited SPP modes propagating through the silicon core. Mathematical analysis of the SPP based TMI device has been carried out using a mathematical model based on effective index methods. The optical pulse dependent coupling characteristics of the SPTMI coupler is studied with the help of the mathematical model.

The coupling length required to change cross state and bar state coupling in the proposed device by application of an optical pulse is estimated as $92.35\mu m$ which is about ~ 8.4 times [122], ~ 13.7 times [120] and ~ 22.4 times [118] less than previously reported works. Considering access waveguides with transition length $L_T = 24.97\mu m$ and bending loss $0.1dB$ (bending radius $R = 39\mu m$ and bending height $H_T = 4\mu m$), the total length of the device is obtained as $L_D = 142.29\mu m$ which is ~ 5.9 times compact than that of previous work [122]. The optical pulse energy required to change cross state coupling to bar state coupling is found to be $16.4pJ$ which is ~ 1.3 times lower than that in a previously reported work [122]. The cross talk in the device is found to be very low ($\sim -47.3dB$)

which is ~ 2.24 times less than previously reported devices [120,122]. Moreover, the switching time of the device is expected to be of the order of picoseconds.

We have shown applications of the proposed surface plasmonic TMI waveguide coupler to realize all-optical logic operations. All-optical fundamental logic gates are implemented by using the 2×2 SPTMI waveguide coupler. By using the power launched in one of the input access waveguides as control signal and optical pulse energy applied in cladding region and optical power launched into the other access waveguide as input signals, all-optical fundamental NOT, AND and OR logic operations have been realized. The output states of logic gates are obtained at either one of the output access waveguides. By cascading two stages of SPTMI waveguide coupler, we have proposed new structure for universal gates and demonstrated NAND and NOR logic operation by considering proper control signals. The NOR and NAND operations can be realized simultaneously using the proposed cascaded structure. Using the same new structure, we have also demonstrated XOR logic operation by having proper control and input signals.

The length of the coupling region for implementation of fundamental NOT, AND and OR logic gates is obtained as $92.35\mu m$ which is about ~ 53.9 times [69] and ~ 8.4 times [67] less than that in previously reported works for realization of all-optical logic operations. With input and output access waveguides having transition length $L_T = 24.97\mu m$ and bending loss $0.1dB$, total length of the SPTMI waveguide coupler for fundamental logic gate operations is obtained as $\sim 142.29\mu m$ which is about ~ 41.7 times [69] less and ~ 5.9 times [67] less than that in previously reported works for all-optical logic gates. The operating time of the logic gates is of the order of picoseconds and the power consumption is $16.4pJ$ which is about ~ 1.65 times less than that in previously reported gates [67]. Selection of NOT, AND or OR logic functions are made by the presence or absence of optical pulse applied at the nonlinear cladding and power at the input access waveguides. Because these proposed all-optical logic gates do not depend on the phase difference of input signals, the designed gates are free from any instability that can be caused by any unwanted variation of input phase difference.

Using the basic surface plasmonic two-mode interference (SPTMI) waveguide coupler, an optically-tunable 3dB power splitter has been designed. The power splitting ratio of the 1×2 SPTMI waveguide coupler based 3dB optical power splitter depends on the energy of optical pulse applied at the GaAsInP cladding of the SPTMI waveguide coupler. By increasing the energy of applied optical pulse, tunability of the proposed power splitter is achieved and the power splitting ratio can be varied in a wide range from 50% : 50% (3dB coupling state) to 1% : 99% or 99% : 1% by varying the energy of optical pulse from 0 to $8pJ$.

The length of the coupling region of the 1×2 SPTMI waveguide coupler based 3dB tunable optical power splitter is obtained as $93.85\mu m$ which is about ~ 11.5 times less than that of a previously reported variable optical power splitter [93]. The total length of the proposed 3dB tunable optical power splitter with access waveguides having transition length of $24.97\mu m$ and bending loss of $0.1dB$ is estimated as $143.79\mu m$ which is about $\sim$ 69.5 times and $\sim$ 1.4 times less than previously reported works on variable optical power splitter [97, 98]. The proposed device is free from drawbacks such as narrow tuning range, discrete power splitting ratio, and tunability dependence on device parameters seen in previous works [57, 92, 95, 102, 103, 105]. The power consumption in the device is $\sim 0 - 8pJ$, whereas the operating time is of the order of picoseconds.

6.2 Scope for future work

In this work, we have discussed only fundamental logic gates AND, NOT and OR gates and universal logic gates NAND and NOR gates using the proposed SPTMI component along with XOR gates. There are ample scopes of the use of these gates in different blocks of optical processor such as ALU, memory (register and counter) etc. For these building blocks, it is also required to decrease the size of our proposed SPTMI component. For further reduction of size, new structures such as tapered geometry [133, 134], S-bend geometry [135] and tooth shaped geometry [136, 137] are necessary to study. Although we have studied the possibility of use of SPTMI structure for key devices of optical processor such as all-optical logic gates and optical splitters, the experimental implementations of these devices are important task of research. For implementation of these devices, one may search new materials along with technology.