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# DETERMINATION OF SUITABLE MATERIAL TO CONTROL OF LIGHT

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## ABSTRACT

This article presents the techniques of determination of suitable material to control of light such as generating slow, fast pulse using nano ring resonator. Nano ring resonator systems made of different materials. Nano ring device can be constructed with radius in the size of a nano meter. The concepts behind optical ring resonators are the same as those behind whispering galleries except that they use light and obey the properties behind constructive interference and total internal reflection. In this research, ring resonators are made of InGaAsP/InP, GaAlAs/GaAs and hydrogenated amorphous silicon (a-Si:H) materials.

**Keyword: Hydrogenated Amorphous Silicon, Semiconductor, Absorption**

## INTRODUCTION

The nanotechnology has attracted many researchers **[1-4]**. The important effects of InGaAsP/InP, GaAlAs/ GaAs and hydrogenated amorphous silicon (a-Si:H) materials are dispersion and nonlinearity in optical waveguide while the pulse fed into nano ring. Each optical ring resonator behaves in many way slike a Fabry-Perot cavity **[5-8]**. Fabrication of In GaAs/InP waveguide is based on the semiconductor materials. In designing material and device structures for waveguide modulators, one has to consider various physical constraints limiting the microwave intensity **[9-11]**, output power, the modulation depth, and the bandwidth. The capacitance of the modulator must be minimized for wide bandwidth consideration **[12-13]**. Recently, a variety of GaAs/AlGaAs waveguide devices have been reported, including directional couplers, nanoring resonators and photonic crystal cavities **[6-8]**.

Interest in hydrogenated amorphous silicon as a material for the realization of optical interconnects in integrated circuits was initially proposed with the demonstration of an optical tunable a-Si:H planar waveguide based Fabry-Perot intensity modulator **[8-14]**. The a-Si:H is an alternative material which can be used for integration of silicon photonics. It allows amorphous silicon to be integrated at any point in the fabrication process with minimal complexity enabling vertical stacking of optical interconnects **[15]**. Low loss waveguides including cavity resonators have been demonstrated using amorphous silicon **[16]**.

The physical system of three waveguides based on semiconductor materials has been reported at 1.5 µm center wavelength in **Table 1**.

**Control of Light Based on Dispersive Waveguide**

The Kramers–Kronig relations are bidirectional mathematical relations, connecting the real and imaginary parts of any complex function that is analytic in the upper half-plane. These relations are often used to calculate the real part from the imaginary part (or vice versa) in physical systems **[17]**. The Kramers–Kronigrelations is derived by considering the integral as given in Equation (1).

$$I = P\int_{-\infty}^{+\infty}\frac{\chi(\omega')}{\omega'-\omega}dx \quad \text{………………(1)}$$

*P* shows the principal value of the integral and *I* represents the integral values. Here, $\omega'$ represents the complex angular frequency and $\chi(\omega')$ shows the dielectric susceptibility. And these Kramers–Kronig mathematical relations are used to examine the dispersion of material. For generation fast and slow light, the depressive medium or waveguide is required and the dispersion of the waveguide is tested by this method.

A crucial observation is that the physics behind fast light is identical to the physics behind slow light. Although most of us readily accept the notion of a pulse of light moving through a dispersive material at a group velocity less than c, many of us are uncomfortable with the fast light case. Both arise from the same effect. The shifting of the point of constructive interference is to another point in space time. To understand the remarkable slow and fast light properties of pulse propagation in nano ring resonator systems, the Kramers-Kronig relation connects the real and the imaginary parts of complex response functions of physical systems **[18]**. In this study three materials have been considered as waveguides. The solutions of the wave equation, in this manner, the refractive index is modified and simulated by Equations (2) to (5).

$$n = \sqrt{1+4\pi\chi} \quad \text{……………..(2)}$$

where $\chi$ is the susceptibility.

The refractive index $n = n' + in''$ can be expressed as:

$$n \cong 1+2\pi\chi \quad \text{………(3)}$$

The real and imaginary parts are given by

$$n' = 1+\delta_{\max}\frac{2(\omega_0-\omega)\gamma}{(\omega_0-\omega)^2+\gamma^2} \quad \text{…..} \quad (4)$$

$$n'' = \delta_{\max}\frac{\gamma^2}{(\omega_0-\omega)^2+\gamma^2} \quad \text{……} \quad (5)$$

For a near resonant light field, the transition frequency is denoted by $\omega_0$, 2γ is the width (FWHM) of the resonance. $\delta_{\max}$ is the maximum deviation of the phase index. The group index can be expressed in Equation (6).

$$n_g = n' + \omega\frac{dn'}{d\omega} \quad \text{……………..(6)}$$

The optical waveguide can be used efficiently for the group velocity alteration. The greatadvantage of waveguide is that they can act as slow or fastlight medium directly. Thus, theyare benefit into optical information and communicationsystems **[19-20]**. Furthermore, there are many inexpensive and reliable fiber types with different properties available that makes them very flexible to apply. Another important feature is that theslow and fastlight effect occurs within dispersive optical waveguide which are used in optical communications. For control light nanoring resonate has been used.

## METHODOLOGY AND PRINCIPLE OPERATION

An optical ring resonator is a set of waveguides in which at least one is a closed loop coupled some sort of light input and output. When a beam of light passes through a wave guide as shown in the graph on the right, part of light will be coupled into the optical ring resonator. One frequently chosen way of modeling the response of a single nano ring is the use of a scattering matrix **[21]** as illustrated in **Figure 1**. In the scattering matrix model the nano ring is modeled as one coupler, which couple a fraction κ over to the cross and direct path. The optical fields in the inputs and outputs of the ring are related as follows:

$$\begin{bmatrix} E_1 \\ E_{out} \end{bmatrix} = \begin{bmatrix} A & B \\ B & A \end{bmatrix} \begin{bmatrix} E_2 \\ E_{in} \end{bmatrix} \quad \text{……(7)}$$

$$E_1 = AE_2 + BE_{in} \quad \text{.............(8)}$$

$$E_{out} = BE_2 + AE_{in} \quad \text{............(9)}$$

The parameters such as A and B are the coupler coefficient in direct and cross path as follows:

$$A = \sqrt{1-\kappa}, B = j\sqrt{\kappa} \quad \text{.............(10)}$$

In this method the waveguide is symmetric and coupling is lossless. Lossless coupling is when no light is transmitted all the way through input waveguide to its own output and all of the light is coupled into the ring waveguide. For lossless coupling to occur, the following equation must be satisfied:

$$|A|^2 + |B|^2 = 1 \quad \text{............(11)}$$

where A is the transmission coefficient through the coupler and B is the cross transmission coupling referred to as the coupling coefficient. With the scattering matrix model, the influence of the loss parameter on the nano ring response can be determined as well. Parameters such as filtering bandwidth, insertion loss, crosstalk, and channel separation can be determined in this way.

For simplification of the equation, the output fieldat steady state is given as:

$$y_1 = \sqrt{1-\kappa_1}, x_1 = \sqrt{1-\gamma_1}, \tau = \exp(-\alpha L/2), \phi = kLn_0 + kLn_2|E_1|^2 \quad \text{..(12)}$$

Here, α and γ is the absorption coefficient and fractional coupling intensity loss respectively. L is the circumference of each ring and $\phi$ is the linear and nonlinear phase shift. $\kappa_1$ is the coupling coefficient and $k = \frac{2\pi}{\lambda}$ is the wave propagation number in a vacuum. $\tau$ is a one round trip loss. The transfer function of this configuration is derived by the scattering matrix method **[21-22]**. The light in the ring resonator filter is incorporated in the attenuation constant, the interaction can be described. The output electric field can be calculated via scattering matrix method as follows:

$$E_{out} = E_{in} y_1 x_1 + j\sqrt{\kappa_1} x_1 E_2 \quad \text{............(13)}$$

E1 and E2 are in the electric field of ring resonators that there are defined as

$$E_1 = j\sqrt{\kappa_1} x_1 E_{in} + E_2 x_1 y_1 \quad \text{.............(14)}$$

$$E_2 = E_1 \tau \exp(-j\phi) \quad \text{..................(15)}$$

$$E_1 = j\sqrt{\kappa_1} x_1 E_{in} + E_1 x_1 y_1 \tau \exp(-j\phi) \quad \text{.......(16)}$$

$$E_1 = \frac{j\sqrt{\kappa_1} x_1 E_{in}}{1 - x_1 y_1 \tau \exp(-j\phi)} \quad \text{.............(17)}$$

The output field obtained as:

$$E_{out} = E_{in} y_1 x_1 + j\sqrt{\kappa_1} x_1 \tau \exp(-j\phi)\left(\frac{j\sqrt{\kappa_1} x_1 E_{in}}{1 - x_1 y_1 \tau \exp(-j\phi)}\right) \quad \text{...(18)}$$

The ratio between output and input can be achieved as:

$$T = \frac{E_{out}}{E_{in}} = \left(\frac{x_1 y_1 - x_1^2 \tau \exp(-j\phi)}{1 - x_1 y_1 \tau \exp(-j\phi)}\right) \quad \ldots\ldots (19)$$

The external phase shift of MRRs can be achieved from the argument on ratio output field and input field as **[23]**:

$$\Phi = \arg\left(\frac{E_{out}}{E_{in}}\right) = -i \log\left(\frac{T}{|T|}\right) \quad \ldots\ldots\ldots\ldots(20)$$

Here, the boundary condition should be achieved. If $0 \langle \left(\frac{T}{|T|}\right) \rangle 1$, the external shift phase is positive. Therefore in the pulse will be slow. In this condition roundtrip loss must be bigger than coupling coefficient. Internal phase shift of nano ring is given by $(\phi = \omega_0 T_R)$, where $\omega_0$ is one of the resonance frequencies of the resonators and $T_R$ is the transit time of the resonator. The phase sensitivity is obtained by differentiating the external phase shift **[24]**.

$$\Phi' = \frac{d\Phi}{d\phi} = \frac{(1 - x_1^2 y_1^2)\tau^2}{1 - 2x_1 y_1 \tau \cos\phi(\frac{1+\tau^2)}{2} + \tau^2 x_1^2 y_1^2 + x_1^2 y_1^2 (\sin^2(\phi)(1-\tau^2)^2) - (1-\tau^2)} \quad \ldots.(21)$$

Therefore the group delay of the ring resonator can be achieved by radian frequency of the transfer function and is defined as:

$$T_D = \frac{d\Phi}{d\omega} = \frac{d\Phi}{d\phi}\frac{d\phi}{d\omega} = \Phi' T_R \quad \ldots\ldots..(22)$$

$$T_D = \frac{(1 - x_1^2 y_1^2)\tau^2}{1 - 2x_1 y_1 \tau \cos\phi(\frac{1+\tau^2)}{2} + \tau^2 x_1^2 y_1^2 + x_1^2 y_1^2 (\sin^2(\phi)(1-\tau^2)^2) - (1-\tau^2)} \frac{n_g L}{c} \quad (23)$$

Here, $n_g$ is the group refractive index. This equation shows that the group delay achieves its maximum in the resonance wavelength. It is reduced when it detune from resonance. The group index of the materials depends on the dispersion term ($\frac{dn}{d\omega}$). If $\frac{dn}{d\omega} \rangle 0$ the dispersion is normal and point of constructive interference occurs at a later time. Therefore slow light is generated. Here the time delay and backward shift time due to the propagation through the nano ring can be calculated as:

$$\Delta T = NT_R + T_D$$

Here, N is number of roundtrip and L is the circumference of the ring. This relation shows that the group delay is inversely proportional to the group velocity. Therefore, the generation of slow light for optical buffer and read only memory is realized. Here, to generate slow light, series of ring resonators is used. In this method, the nonlinear effect of waveguide is neglected. Therefore the determination of shift phase is caused by observed time delay. Time delay can be obtained using shift phase and it shows the rate of slow light in this method. The mathematical analysis of ring is mentioned in last section as a single ring resonator.

## Simulation Results of Light control in Waveguides

All optical waveguide materials to generate slow and fast light should be dispersive. This means that the refractive index varies with wavelength. There are several ways to measure dispersion in materials. A simple measure is the Abbe number ($V_D$). Another measure of dispersion is the derivative $dn/d\lambda$. Besides absorption resonances, amplification processes are also applicable to induce a material dispersion. Hence, optical waveguide can be used for slow and fastlight generation. Dispersion is most often described for light waves, but it may occur for any kind of wave that interacts with a medium or passes through an inhomogeneous geometry. In this study, three waveguide have been used as dispersion material. They have capability of high bandwidth while the maximum achievable time delay is small compared to other mechanisms. The classical phase shift is determined solely by the angular velocity, the optical frequency, and the area is near resonance and completely independent of the medium's other properties such as the index of refraction and its dispersion properties. The refractive index as a real part versus wavelength is simulated using Kramers-Kronig relation method for three materials which has shown in **Figure 1**. Here consider a nanoring resonator by radius 50 nm. These results show the variation of refractive index is maximized in near resonance based on the physical materials as waveguides. The a-S:H waveguide have the maximum variation refractive index. Figure 1demonstrates negative and positive group refractive index. It shows the variation of group refractive index versus wavelength. It illustrates in the positive area in shoulder of the curve, the light can be slow down and in the negative area the light can be fast up. It shows that the most variation of refractive index occurs in near resonance. When light travels in negative index then it can be fast up, and at the positive index can be slow down. According to **Figures 2 and 3**, frequency region close to resonance wavelength can be used to generate slow and fast light.

The scattering process only occurs over a narrow range of frequencies, which means that the control beam creates a resonant region in which the response of the waveguide to light is maximal. This resonance has a width of approximately 10 MHz in a standard telecommunications optical waveguide. However, a big advantage of this approach is that the central frequency of the resonance that is responsible for the slow and fast light effect can be changed by simply changing the frequency of the control beam. The adjustable behavior of the group velocity can be used to engineer systems with large externally controllable dispersion, where $\frac{dn}{d\omega}$ have very large positive or negative values. Therefore it was possible to propagate pulses faster or slower. In a spectral area of normal dispersion ( $\frac{dn}{d\omega}\rangle 0$ ) the group velocity decreases. In the waveguide each wave of different frequency propagates with different phase velocity,If $\frac{dn}{d\omega}\langle 0$ , the group velocity can even become negative. In this case the pulse propagation becomes fast light. On the shoulder of the curve, the group index is more than one. Therefore in this area, the pulse propagation becomes slow down.Near the resonance the slope of the curve becomes very steep indicating that the phase is sensitive. **Figure 4** shows the variation of the dispersion versus wavelength.

Near each resonance the shift phase varies rapidly with the frequency leading to reduce the group velocity Therefore in the range of wavelengths which are close to resonance, the light can be fast up and in the shoulder the light can be slow down. **Figure 5** shows the variation of group velocity versus waveguides. It shows that the fast light can be achieved near resonance wavelength. This effect appears in a range of wavelengths which are close to the resonance wavelengths of the material.

The variation linear absorption coefficient (α) can be obtained and simulated is shown in **Figure 6**. In the wavelength resonance, the absorption is the maximum. Large absorption coefficient occurs at near resonance frequencies where a-Si:H is the largest absorption coefficient in these materials. The results show that the best center wavelength to use in input pulse for these waveguides is 1.5 µm.

The paper deals with a specific organization form of matter. Other forms and description are given in the work of researchers **[25-30]**. In most cases quantum theory **[31]** is necessary for the description of the organization forms of matter. But even the interpretation of modern quantum theory seems still to be an open question, as is demonstrated in some work **[28-32]**.

**Table 1: Physical materials**

| Properties | InGaAsP/InP | GaAlAs/GaAs | a-Si:H |
|---|---|---|---|
| Core refractive index | 3.34 | 3.37 | 3.48 |
| Clad refractive index | 3.17 | 3.14 | 3.1 |
| Core area | 0.1 – 0.9 $\mu m^2$ | 0.085-0.9 $\mu m^2$ | 0.1-0.9 $\mu m^2$ |
| Nonlinear refractive index | $3.2\times10^{-17} m^2 W^{-1}$ | $5.4\times10^{-18} m^2 W^{-1}$ | $4.2\times10^{-17} m^2 W^{-1}$ |
| Absorption | 20 dB/cm | 0.9dB/cm | 3.5dB/cm |
| Center Wavelength | 1.5 μm | 1.5 μm | 1.5 μm |

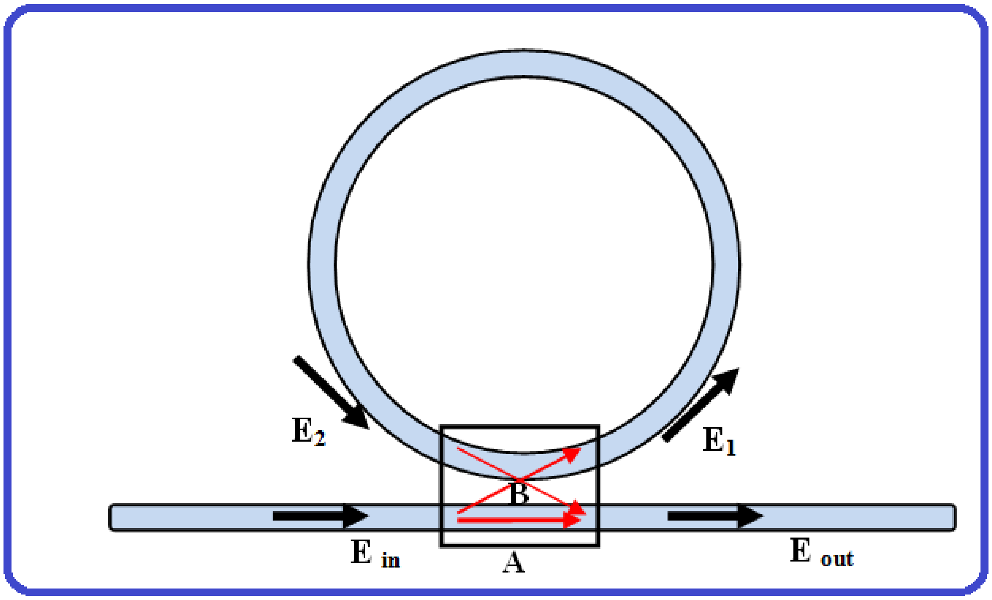


**Figure 1: Scattering matrix model of a nanoring resonator**

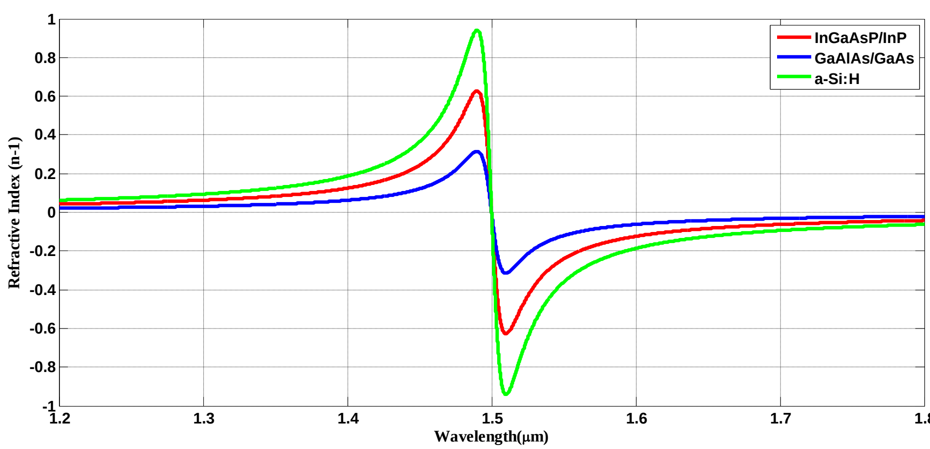


**Figure 2: The variation of refractive index versus wavelength in three waveguide**

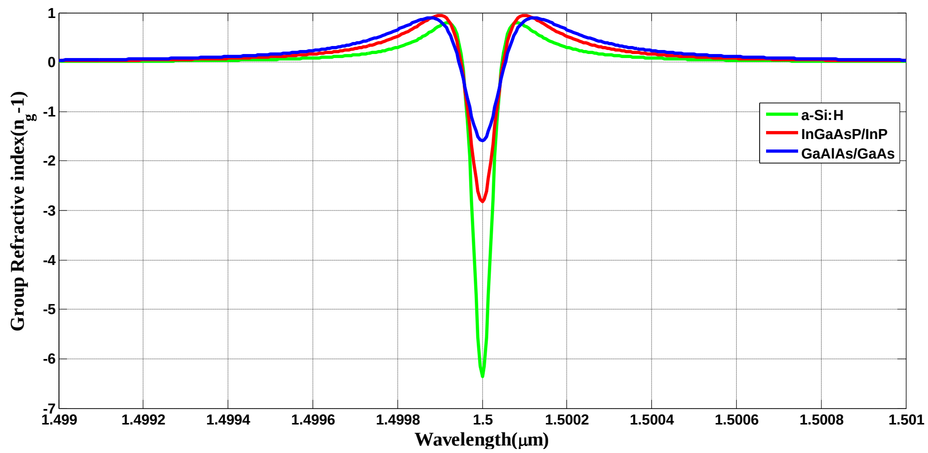


**Figure 3: Schematic of variation group index in three waveguide against wavelength**

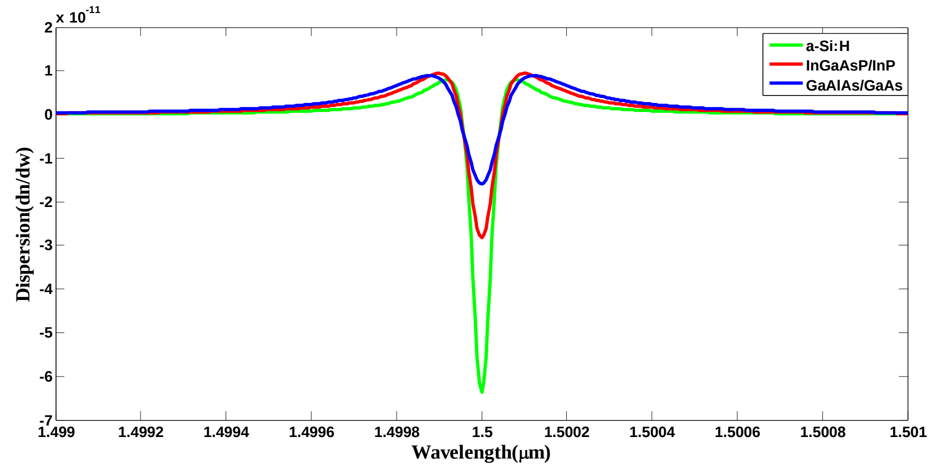


**Figure 4: Variation of dispersion in waveguide versus wavelength**

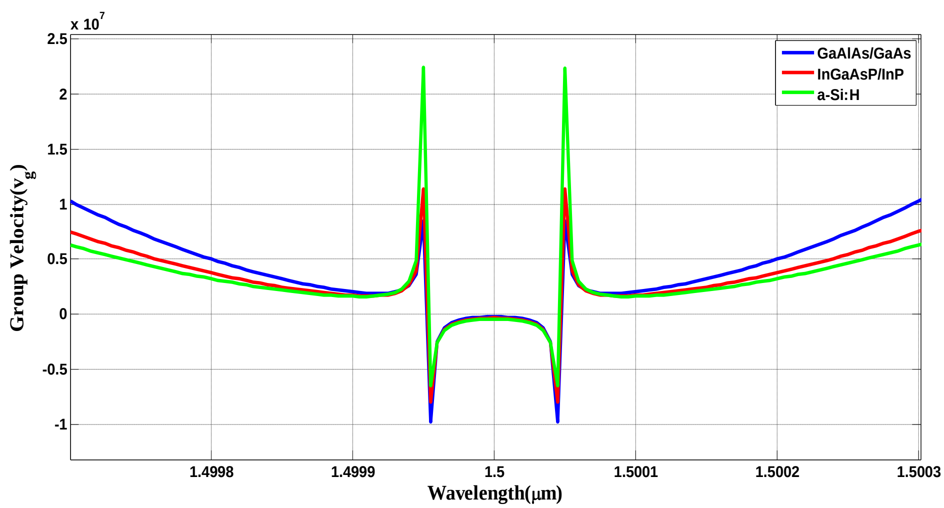


**Figure 5: Variation of group velocity in waveguide near resonance versus wavelength**

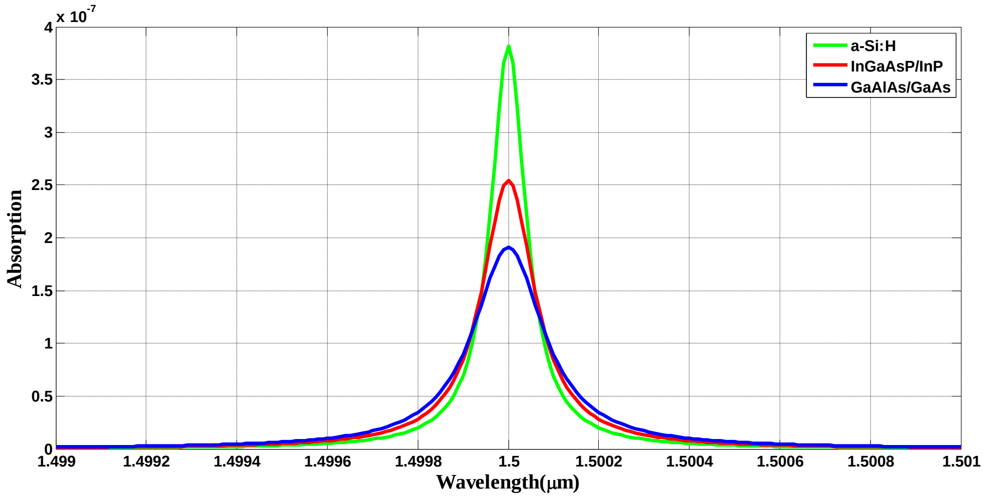


**Figure 6: The variation of absorption in three waveguide versus wavelength**

## CONCLUSION

The simulation results show the best center wavelength is 1.5 μm. In this wave length absorption is maximum. Hydrogenated amorphous silicon is the best material for ring in this center wavelength. For group velocity hydrogenated amorphous silicon is the best material for making nanoring resonator. The maximum dispersion belongs to hydrogenated amorphous silicon. Therefore hydrogenated amorphous silicon is suitable for control of light.

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