Indian Institute of Science

Photonic Integrated Circuits

Lecture – 12
Ring Resonators

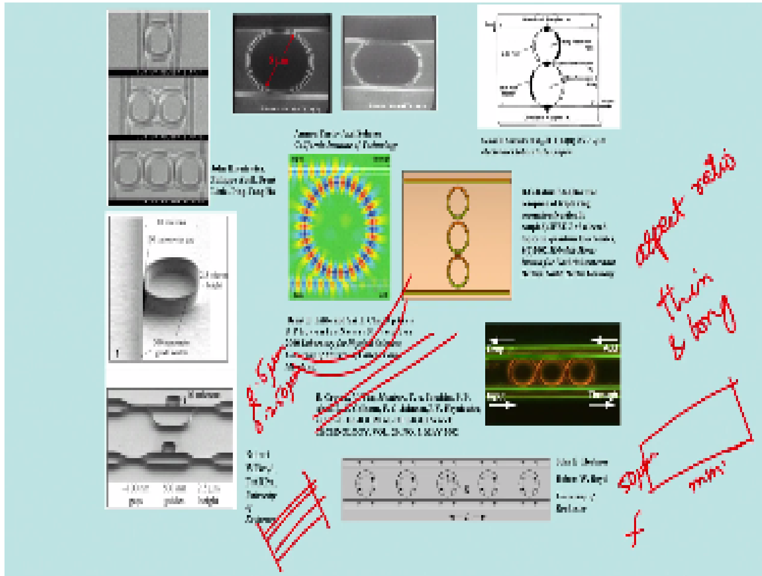
T. Srinivas
Department of Electronics Communication Engineering
Indian Institute of Science, Bangalore.

NPTEL online certification course

This topic is called ring resonators.

(Refer Slide Time: 00:18)

(Refer Slide Time: 00:21)



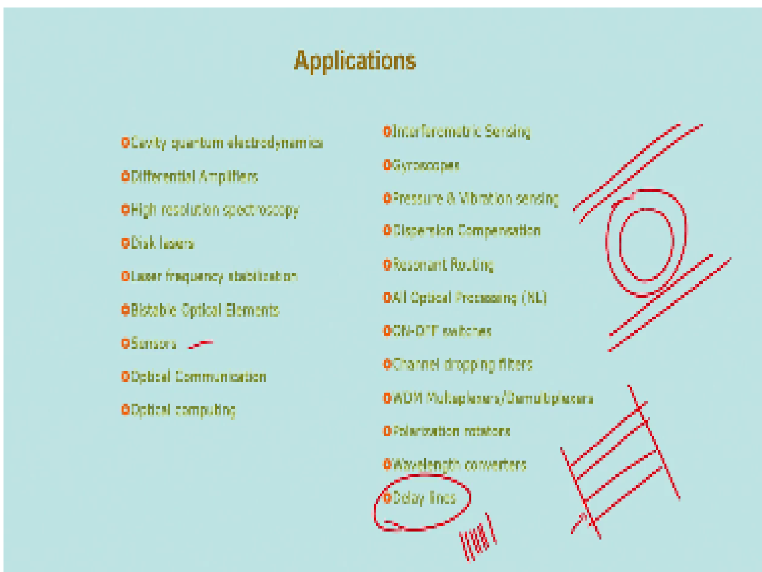
One of the important problems of integrated optical conventional integrate optical device is the accept ratio. So the device is like the MZI the directional coupler the waveguides these are all thick and long angles are very small of the arras of a few degrees. So due to this we are not able to use the chip area very effectively, now we take a typical conventional integrate optical devices the cross section is of the arcs of the few microns say 50micron whereas the length is the arcs of several mm.

Due to this we are not able to choose a chip effect to area very effectively one of the solutions for this CSE ring resonators have a waveguide in the form of arrange like this and you have several bus waveguides this is the straight waveguides are call the bus waveguides to launch light in to and out of the ring resonators. So there are many, many configurations many variation and many, many applications so several of them are being shown here for example the double ring resonators that triple ring couple resonators and here is an area of resonators coupled the light is launched in to this and then can be caped out across other ports.

One of the important features of the ring resonator is the resonator frequency as I will shown you next slide it can operate only a particular frequency. So this is a frequency dependent device that means that provides lot of applications and uses the variation of this is call as the raise resonator where you have a long length for coupling between the ring and the waveguide this is another important feature that we absorb that there is a straight waveguide and a curved waveguide or the circular waveguide couple to the ring it is unlike the straight l\waveguide coupling that we have noted earlier.

In earlier directional coupler we have noted two waveguides which are close together but straight, in the case ring resonator you have curved waveguide I will put it in front way you are coupling between the straight waveguide and curved waveguide that makes the mathematics more complicated. And you also see some of the typical ring resonators fabricated that appear in the current literature, typically there of a arcs of a few microns or few tens of microns in the radius and since many of this device are silicon based you know that the waveguides wits are of the arcs of 0.5micron and by 2 50 micron etc, so 500nm/ 250nm typically this highs.

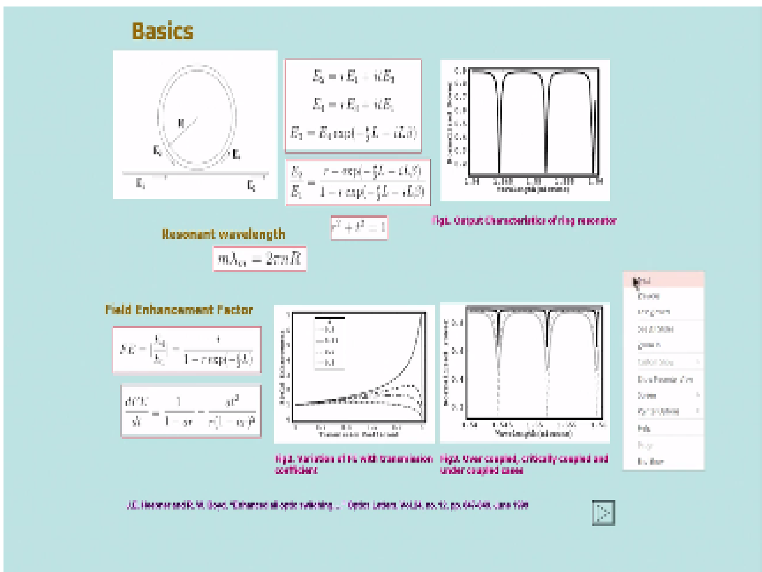
(Refer Slide Time: 03:42)



So there are several application that I am showing here so ring resonator has become a multi functional device you can use it for many purposes like a directional coupler, we have noted that a directional coupler could be used a power divider as a switch as a modulator and so on and so far. So similarly and integral optical ring resonator could be used for various purposed I will shown some examples here one of the important applications is call the delay lines it is very difficult to achieve delay on this chip because you have very small length fuse gratings we have good amount of delay and ring resonator is another important way to obtaining good delay line.

These are the applications in the communications to coordinate different signals recognition of the optical header in a communication link and so on so forth, so I will highlight another important applications arcs you can make sensor out of the ring resonator as I will showing one of the slides, can also configure the erase suffering for the multiplexing and de multiplexing in a communication link then you can use it ultimately for the quantum information function have put here you can also think of hearing the resonator as a fundamental element building block for quantum information foe all functions which are not highlighting here. So off course in one of the application I have you show that here confident has the logic gate and so on next.

(Refer Slide Time: 5:23)



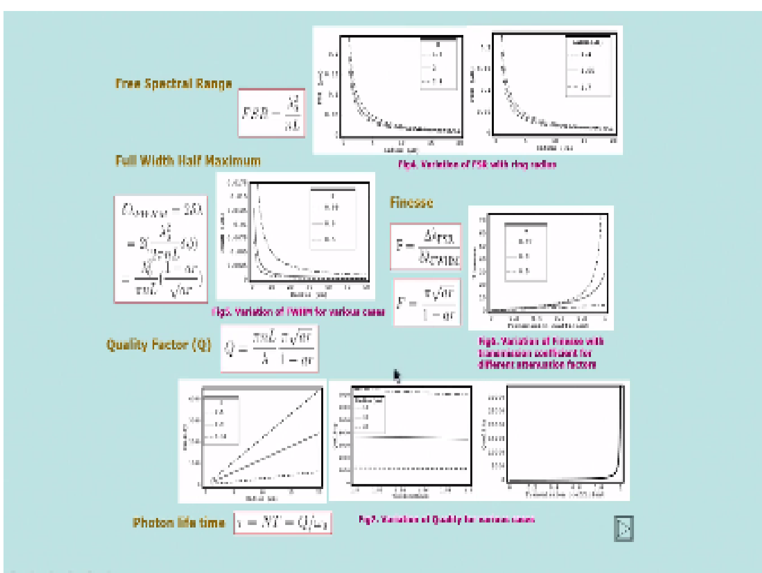
This is light shows some basic property of a integrated optical in the resonator as I said earlier wave guide is a form a link couple to bus but join the property also depend on the radius and the coupling and so for the wave guide design basic design etc so you can use the design geometrical optics approach up to study the properties suffering and s in its single bus and there are electric field even the E2 E3 for the different section of the ring resonator can be upload together.

So there the light could be couple together in to the waveguide and the fraction of it can also go back and the I try it will be there is a senator nominee in the so the work out to that the E2/E1 the amount of the transmitted light spectrum over there spectrum is the transmitted light can be work out in the terms of the radius in the terms of the total length in the term of the ring and the properties and the constant and the refractive index of the ring wave guide one and we observe it are put the characteristics like this for the ring resonator .

On the X-axis you find the operating wave length and the Y axis you have the field amplitude or normalized for you observe that they are in the pattern frequency that they are in the resonator and the lot of the power is extracted out of the ring so you have the expression of the wave length resonant wave length given in the terms of the refractive index of the wave length and the wave guide this can be consider as a effective refractive index of the wave light or it is the refractive convection of and T is the transmission coefficient and the award is called as the inside the ring which is defined in the terms of the field let us coupled in to the ring with the respect to the light is lost .

If more power is in to the ring then you can say the ring of much more enhanced it is because round in the round and you can say the totally density of the field and more than the one that is injected to the concentration of the power. So there are the expression of the field enhancement and the field enhancement factor you can looker-on the current literature and this expression for the transmission and the coefficient of the function felid enhancement is the function of the transmission, similarly the several cases of the operation of the device like the over coupled the system the cryptically is the opened system and the under coupled system and so on.

(Refer Slide Time: 08:07)

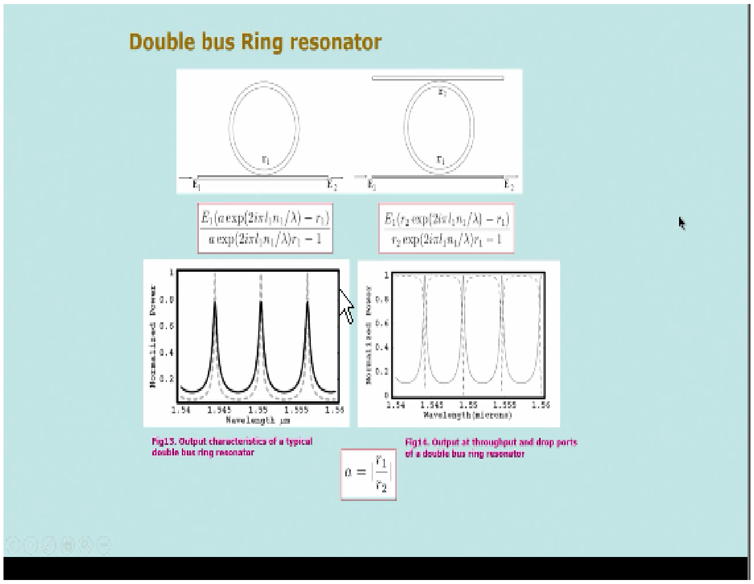


So this are the further properties another important property of the resonant of the resonant of the free spectral lines which is that the distance between the resonant ring which could be given in the operating and in to effect of the refractive index of total length of the ring, so you observer the radius of the free spectral range reduces as increase the radius the peaks get close which means the survives in the technologies and the footed here, the radius also free spectrum in the different values of the operating wave length for the different rotating values.

You can find the plot of the free spectral range son the radius similarly the spectral width of to spectrum is very important for the many application we will be very sharp spectrum and it can be given in the tremor the difference in the wave length of the just tell you suppose we have the length is3D full depth or the half maximum can be defined ashen point were field falls of .So this half for the point anthem width point is the full width and the half of the maximum so if that the half maxims cane given in radius and the other factored so closely related to the full width and the half width and the quality factor which can be defined in the terms of reciprocal proportion.

To the reciprocal of that fluid to the half maximums you also called fineness of the spectrum and also a variation photon life time photon the drink, so drink photon is stain longer which important function for various applications is and we have various of the quality factor for various along with the wave length along with transmission requisition and so on so typical quality factors of the arc for the 7000 and almost very little variation of the wave length. So it is very good features that why is the draw backs.

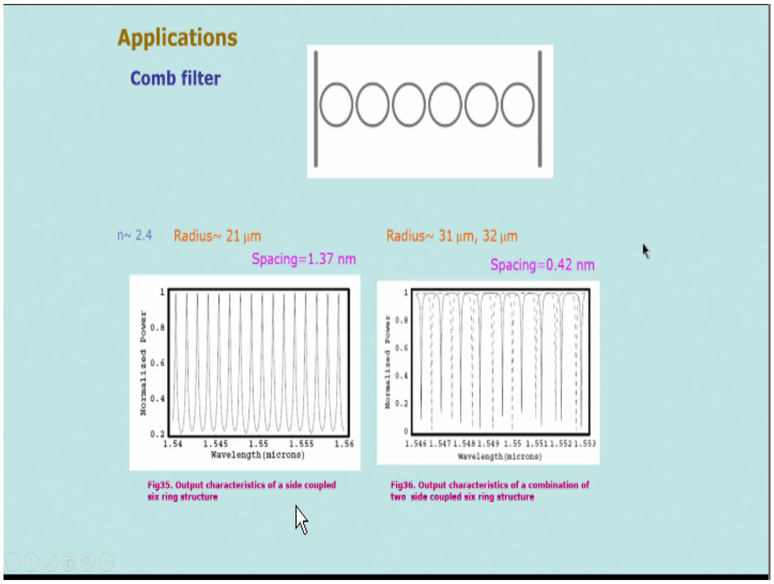
(Refer Slide Time: 10:38



So these example what is called double bus ring resonator, there are single bus resonator configuration where the expression for the resonate frequency are given like this. And the double ring where we launch like this. And we can use other part E2,E3,E4 to measure the output. This is called the backward effective report. We can observe this one of the most common configurations and so on.

There is different coupling the reflection of the coupling of the crossing of each of these. We can across the resonator double ring, double bus in where both the couplings at this wavelength as well as the wavelength of enough, so for in this output characteristics of a typical double bus resonator. I normalized for an x axis and wave length on the other axis. So at the different course the over drop is this one here. At through put and the drop puts, so there complimentary so in the drop put is very sharply and the through put these are the through put. So the raise of the flexi crop easy in else which is.

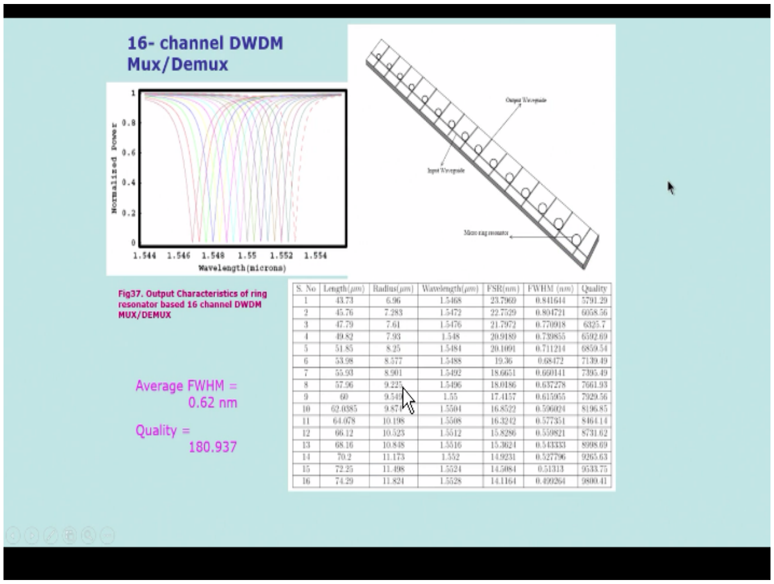
(Refer Slide Time: 11:59)



And there are many applications and filling a couple of applications to comb filter. So we can design the rings to be different radii and couple light. Across these resonator in there are many coupling points and each of these junction the couplings from one width will apply by one ring to other so these to very well utilize to at void is making comb filters. Comb filters is a structure waves, these resonator at many frequencies pores is space frequencies.

So this particular case we observe a comb or the resonator of the radius 21µm spacing that will you can get these spectrum components as 1.37 nm. The first is smaller could be actual should be poplar design in the small extra. This example vary have half nanometer, as the channel spacing in between the different spectral components. So this a first one is a characteristics of a side coupled ring structure in the sense you have coupling fr4om the side and double code coupled ring structure. So there are fleets in between also here. Two side coupled rings and six ring structure, this is six ring structures.

(Refer Slide Time: 13:26)

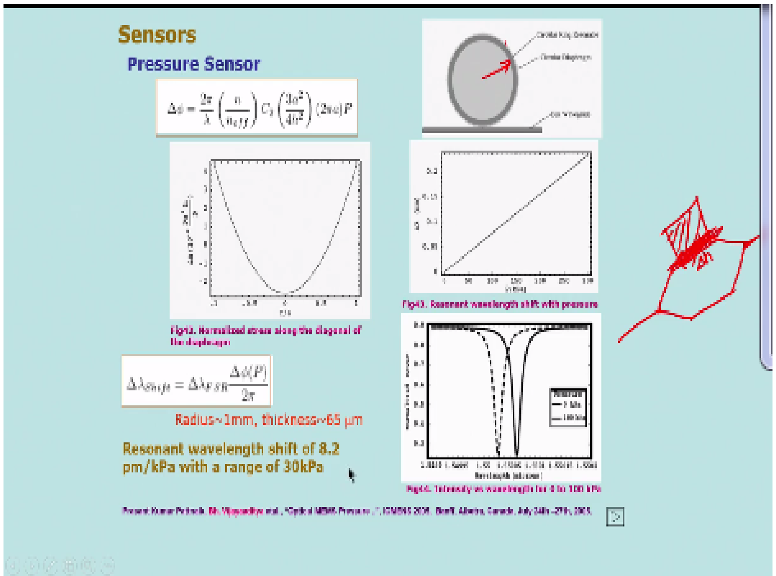


So this a example of sixteen in channel in demux or mux we can configure the ring resonator such that you can achieve the function of demux. The demux function has a function over there we have light long to the input port could be tapped across each of the output ports at different values. By choosing the radius of the rings appropriately we can get the peaks a different parts you can tap the signal. Different ports assuming there is a interesting feature the light is cupped at this junction and at this junction not exactly at the opposite ends.

So the wave weights are placed perpendicular to the coupling and this through the ring and from coupling at that point. So the expressions of the coupling co efficiencies are as shown earlier. So this table shows the various properties with the channel number the length and the radius of the ring. Then the variations of the operation that you can drop it and Fsr and WHM and quality of each these, so from picture you see that they are almost very uniformly distributed and having uniform attenuation,.

So in this the average FWHM is 0.62nm and the quality factors of the arts are 180 this is quite small but it could be achieved, you can achieve very high quality and properties science.

(Refer Slide Time: 15:06)



So this is the example of applications of ring resonator to a pressure sensor we have seen the pressure sensor made on the magzent interferometer earlier, where you had h out deiform, you had earlier interferometer like this and one of the arm of the interferometer below you etch out deiform. In this case from the mechanical energies the stress in the variation maximum in the wave guide, so maximum change in the Δn and the pressure out, optimum pressure out. So in this particular example we use the ring resonator vary how deiform just below the circular dia form.

So that the entire circumference can be utilized, so the analysis will know that the stress is maximum at boundaries, so the reflection is maximum there and so we can have a the ring resonator based precise much more effective and utilizing the elector optic effect various very effectively. So you have the variation of the pressure given by this expression, now the effective waveguide the coupling co efficient and pressure on the right axis.

So you also have the thickness of the die form is h and also the radius of the ring, so this shows the variation of the normalized stress along the radius of the dia form, so you have Δn has a function of radius, so you see that it is very low at this point at the center of the circle and varying into large values at the boundaries. This is only the refractive index as a function of normalized values.

So typical refractive index of the origin of 0.01 so 1% changes in the refractive index is much more then the sufficient to which are very good sensing function. So this is plot where we choose the variation of γ as function of pressure, so when the pressure is incident uniformly in this ring we can expect due trot e reflect index change the present frequency different. So in this particular case I am showing the present frequency which is going down for application of pressure of 100kp.

So when there is pressure applied you have resistance frequency at this point 1.555005 and slightly less, so this Δγ phase shift is important factor which can be used to calibrate your sensor. You can plot the Δγ or assess the incident pressure. You have Δγ of the fraction of nanometer by this is possible for the pressure in the range of several 100 of kilo Pascal. Here the shift is done by the spectral range and Δ is the function of P and the typical radius is of 1mm, by large and thickness.

This is the design which designed for this range of pressure applications, so the wavelength shifts are of 8pm for kpa with a range of 30kPa. So there are several other applications in the next topic photonic band structures we will combine the properties of optical memes that ring resonator and the photonic band structures thank you very much for this module.