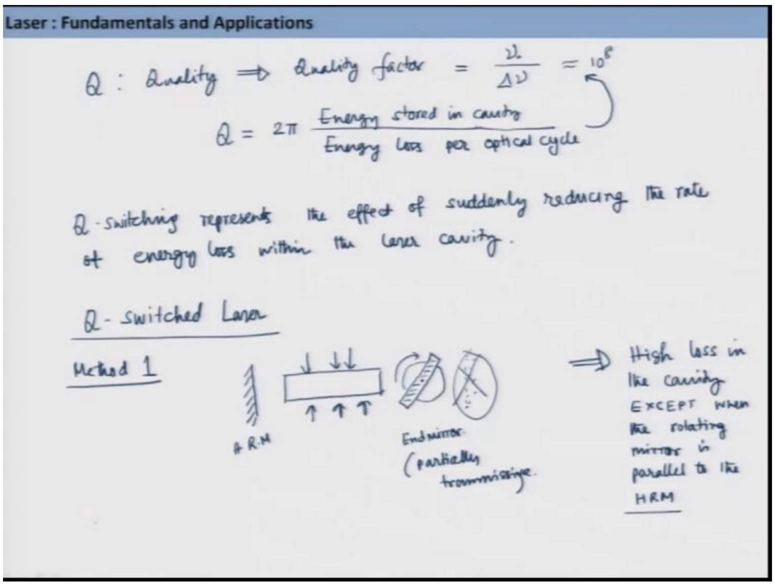
Laser: Fundamentals and Applications
Prof. Manabendra Chandra
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 18
Q-switching and Pockels effect

Hello and welcome back. So, we have been discussing about the pulsing techniques by using which one can make the laser pulsed. So, we have discussed already cavity dumping technique. And then we started talking about another pulsing technique that is Q switching. So, have a let us have a quick recap. So, we said that Q switching it represents the effect of suddenly reducing the rate of energy loss within the laser cavity. And then again you know making the quality of the resonated much better.

So, in case of you know a continuous laser continuous (Refer Time: 00:59) laser if we want to use q switching and make it pulse, what we do we just you know block all the oscillations in the laser cavity. And thereby increasing the loss, and at a given time when enough population inversion has taken place, we allow the oscillation to take place once again that is round trips in the cavity. And a short pulse laser comes out.

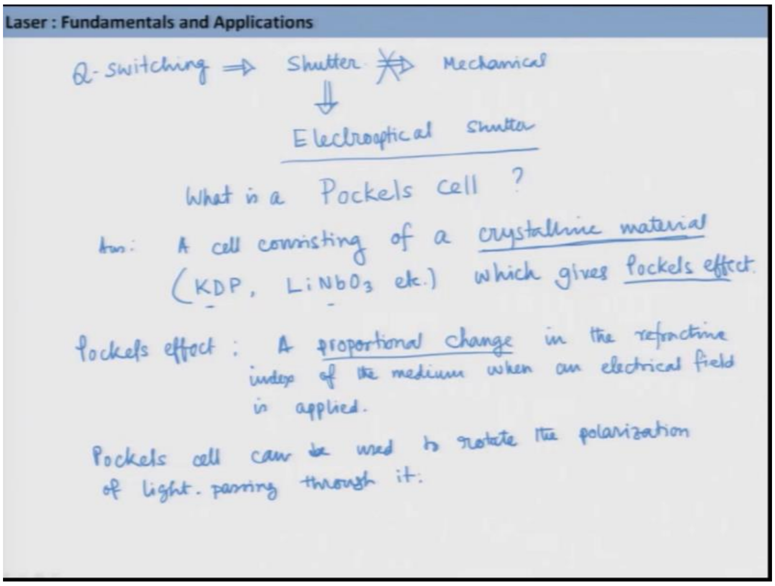
(Refer Slide Time: 01:37)



So, in this case we already said that the pumping rate it has to you know increase so that it has it will exceed the spontaneous decorate. So, that we can have enough population inversion. And another important thing that we should mention here that this Q switching, that is like we showed using a rotating mirror in the previous class. So, these mechanism be it rotating or something else, whichever switches the quality of the cavity this switching rate has to be short enough. So, the switching has time period has to be short enough.

So, for the time being for the time period, when the you know the cavity round trip is allowed that time period has to be very short So that we can get a short pulse. So, the last thing that we would like to mention is that the pulse repetition rate we discussed about it in the previous class. So, the pulse repetition rate that one will get will be totally dependent on the cavity length. So now, with this knowledge what we will do? We will look at the other you know possibilities by which one can achieve Q switching. So, so in real life the q switching is done by using some shutter right.

(Refer Slide Time: 03:26)



So, it is done using some shutter, we have used a rotating mirror in the previous class.

So, I will show you today how in real life this you know shutter mechanism is done. So, in real life this shutter that we used is not a mechanical shutter. So, not like a rotating mirror. So, normally it is not used. Instead what is actually used is something called electro optical shutter. So, you can understand that there will be you know some electric voltage or current the given to the shutter. So, that it can operate it can close an open. So, what is this electro optical shutter that we are talking about? So, this is essentially something called pockels cell.

So, we use a pockel cell inside the laser cavity to get the q switching. So, what is a pockel cell? So, if I ask what is a pockel cell. So, the answer is that pockel cell is a cell consisting of a crystalline material such as say KDP this is potassium dihydrogen phosphate very well known so called non-linear optical crystal. Lithium niobate etcetera which gives pockels effect. So, this is a cell which is essentially crystal something like KDP and lithium niobate and that gives pockels effect. So, the answer is not that clear right. So, we need to know what is pockels effect. So, far you know those people who do not know pockels effect.

So, let me tell you what is pockels effect. So, so the pockels effect is a you know proportional change or linear change in the refractive index within the medium when an electric field is applied. So, it is a it is a proportional change in the RI refractive index of the medium. Here in this particular case this is the crystalline material that we are talking about that is KDP and lithium niobate, when an electric field essential this electric field is quite intensed in practice. When an electric field is applied right. So, this one is a you know linear change of refractive index upon the application of a electric field voltage right. So that means, if I you know apply v amount you know certain amount of voltage then there will be change ineffective index then if I double this voltage then this will also the effecting exchange also will be doubled. So, this a linear process there are you know similar type of electro optical you know materials at present and electro optical phenomena that can be there for example, curve effect. So, in case of curve effect it is a quadratic dependence on the voltage instead of linear dependence.

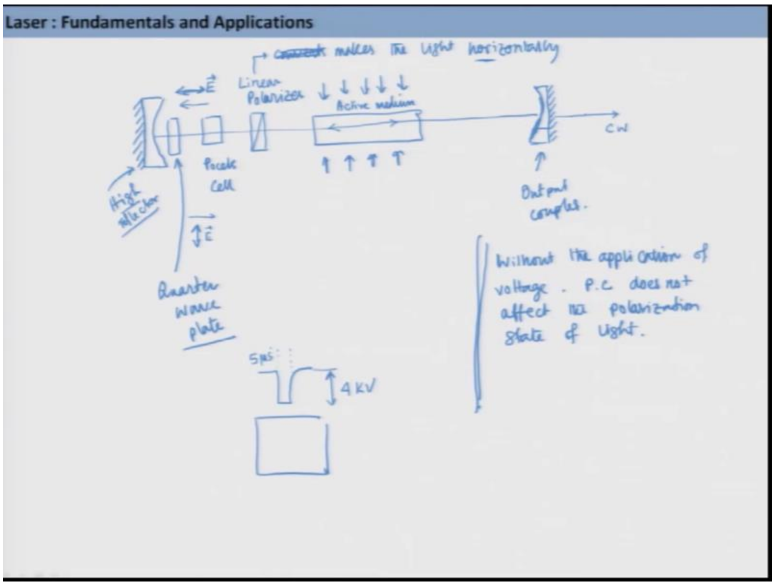
So, right now let us stick to pockels effect which is related to what we want to achieve. So, from this definition of pockels effect what we can figure out that if I apply voltage I can chase a reflective index. So, the you know propagation of light through the medium can be altered by applying a voltage on to this medium and you know not only this just a propagation, but it can also you know affect the polarization state of life. So, I am sure that most of you aware about the term polarization particular in the context of light, but in case if you a not familiar you know I will just mention in you know couple of lines.

So, light is an electromagnetic field; that means, it has an electric filed and magnetic field (Refer Time: 09:59) to this now if there are many photons the electric fields correspond to it is individual photon may be in the same direction or may be in other direction. So, if all of the photons have the electric field align in a particular direction I call this light as a polarized light. So, they are electric field will be osculating in this direction. So, this is not only polarized, but this is called linearly polarized, because if the light is propagating in this direction and you are looking at light propagation reaction then you will see the electric effector like a line.

It is also called a plane polarized light, because if you look at all the osculation and you can figure out if you are looking from this particular direction then you will see this plane contains all the electric field vectors. So, this is also called plane polarized. So now this pockel cell this pockel cell when you apply voltage it can alter the polarization state of light, what thus mean that suppose I am coming with linearly polarized light or plane polarized light both are same. And it goes through this pockel cell that is my lithium niobate crystal or KDP, and I am applying some voltage to it. So, what we will happen it can actually rotate the planer polarization. So, this is for linearly polarized light. Now so, let me just write down so what pockel cell can be done. So, pockel cell can be used to alter or rotate the polarization of light. The light which passes through it. So, light passing through it let us be explicit. So, this much knowledge is good enough for now to move ahead. So, just I will you know remind you once again that in case of q switching we are you know switching the quality of the cavity and thereby we are storing all the energy in the active medium right. So, this active medium stores all the energy in the very similar way to a capacitor which stores all the electrical energy right. So, you know this analogy should help you understanding this q switching process in a much better way.

So now let us come back to the design of the laser cavity when we want to use the pockel cell. So, what we have we have high reflecting mirror ok.

(Refer Slide Time: 13:18)



You can use you know flat mirror you can use concave mirror. So, we have been using flat mirror all the time. So, I will this time use a concave mirror it does not matter you can use a flat mirror here and it will do the same job. Now we have a same active medium, we have light source which will pump the photons pump the molecules to excite the state. And then I have my output coupler I hope you remember what is an output coupler output coupler is the mirror which is not 100 percent reflective that is partially transmative.

So, essentially so, assume that this is a concave mirror just like this one. So, normally what will happen? It will move back and forth and then I will get my laser output as a continuous wave. Now what I want to do? I want to place my pockel cell. So, this is my pockel cell which I want to introduce in the cavity. And I want to use this pockel cell to act as a switch. So, what I need to do for that. So, pockel cell allow will not be able to do it if it has to act as AQ switch we need something else what is a thing we said that we are going to use the you know property of the pockel cell which is it can rotate the plane of polarization of a plane polarized light by certain amount depending on the voltage that is given. So now, within the you know laser cavity the lights are you know coming and going within the cavity. So, if the light is not polarized with generally may not be polarized, what I need to do I need to place a polarizer ok.

So, I will place a polarizer let me be even specific linear polarizer. So, and this is my high reflector and this is my output coupler. So, this linear polarizer what does it do all of you must be familiar with the polarizer what it does you have done experiments in your you know I think plus 2 or may be even in high school where you have used polarizer to make an unpolarized light plane polarized. So, if you have a light which has it is electric field direction oriented in all the possible direction.

So, they are random that is called unpolarized light and from that unpolarized light if you want to make it a plane polarize or linearly polarized light what you have to do you have to create like a gate right. So, through this gate a sudden you know polarized direction will be allowed and the you know outgoing beam will be linearly polarized. So, polarizer essentially does a same thing. So, it is made up of calcite crystal and all which can under a given particular arrangement can convert an unpolarized light to a polarized one. So, this linear polarizer that we are putting here it will convert unpolarized light to a polarized one and that propagates in this direction now ok.

Now, this pockel cell if I do not apply any voltage then it does not do anything to the polarization state of light. So, just we will make a note. So, without the application of voltage pockel cell does not affect the polarization state of light ok. So, this we are making a separate note here. So, to start with I suppose I do not apply any voltage to it, now what I will do? So, the linearly polarized light will go through this pockel cell that is this crystal and it will go hit the high reflector come back and then pass through. So, then I am not doing anything there. So, I need to do something So that this whole assembly of this pockel cell linear polarizer and whatever you know else we want to put. And AQ switch. So, what do we do we essentially put another optics here which is called a quarter wave plate. We will not discuss in detail about the quarter wave plate, but all I will tell you that this is an optics which converts a linearly polarized or which can covert a linearly polarized light into circularly polarized light depending on orientation of the optic access of this quarter wave plate with respect to the polarization direction of the incoming light ok.

So, just for your information if you know if this is the polarization direction of the incoming light and if this is the optic access of this quarter wave plate which can be rotated in this plane, then if this optic access is that 45 degree say I will call it plus 45 degree then it will make one particularly oriented circular polarized light. So, it can be like this. So, say right handed circularly polarized light. If I orient this optic access to minus 45 degree with respect to the plane of polarization of the incoming beam then it will again create a circularly polarized light, but now within left circularly polarized. So, to opposite handedness to circularly polarized light with 2 opposite handedness can be created any other angle. If I put other than this plus and minus 45 degree then it will generate an elliptically polarized light, just for your information.

So, this quarter wave plate if we place in between the high reflector and pockel cell and if I orient it is optical access at 45 degree what will happen? So now, I have an linearly polarized light coming from here. So, let us call this linearly polarized light it converts. So, say it makes the light horizontally polarized. I can put my linear polarizer in whatever wave I can. So, one of them can be horizontal. So, you know plane of polarization will be this one I could do this one. I could do this one whatever I want I can do it, but you know simplicity I can choose either this one or that one. And in most of the lasers particularly (Refer Time: 23:11) laser this plane of polarization is chosen to be horizontal this is in most of the cases not necessarily in all the cases.

So, this linearly polarized light in linearly polarized in the horizontal direction, will pass through the pockel cell and then my quarter wave plate it is optic access is essentially rotated 45 degree with respect to this direction. What will happen? It will create a circularly polarized light does not matter which one may be left circularly polarize or may be right circularly polarized light let us take it is for me left circularly polarized light. So, the left circularly polarized light. So, it will now form a left circularly polarized light and like this it will go and hit this. Once it hit the high reflector and comes back what will happen? A left after turning back it will come in the opposite direction and again it will hit the quarter wave plate.

Now a quarter wave plate can convert a linearly polarized light into a circularly polarized one in a very similar way it can also convert a circularly polarized light to a linearly polarized light when this is again in a particular orientation when the optic access of the circularly quarter wave plate is you know particular orients orientation. So, what is happening here? I know that if I orient my quarter wave plate at 45 degree plus 45 degree I get right circularly polarized light, if I orient it minus 45 degree then it is the opposite one left circularly polarized light. Now if I think in the opposite direction. So, if I send in left circularly polarized light it will be forming a linearly polarized light which is now at 45 minus 45 degree.

If I come with a right circularly polarized light it will come at plus 45 degree. So now, the light which is going through I assume that that is creating left circularly polarized light right. And when it is coming back from the you know the high reflector it is now right circularly polarized light. So, after again passing through this quarter wave plate light will become a linear not only linear the orientation of this linearly polarized light now will be 90 degree with respect to the beam which is going in this direction. So, in this direction when it is going this is horizontal, this is the electric field. So, this is the electric field of right I am talking about.

Now, when this is coming back that is it is coming back in this direction the electric field orientation will be in this direction. Make sense because it is either plus 45 degree or minus 45 degree. So, if I go from right circularly polarized light to left circular polarized light or vice versa, the linearly polarized light is going to shift by 45 plus 45 you goes to 90 degree. So, what happens I get a polarized light which is now coming in this direction toward the pockel cell is vertically polarized, I started with horizontally polarized here right. And horizontally polarized goes to this one form left circularly polarized light hits here comes back becomes a linearly polarize light which is polarized in vertical direction. Now it goes through the pockel cell. Now if the pockel cell is off; that means, if I have not applied any voltage what will happen? Pockel cell will not do anything. So, the vertically polarized light will pass through the pockel cell now as it is and then go and hit the linear polarizer. Now the fun is linear polarizer is you know we enter in this plane because this is allowing only the horizontally polarized light. And now I am sending vertically polarized light what will happen? This will block. So, no light will pass through this polarizer. So, light is coming and going through this one and then ultimately no light is coming out of the polarizer will discard all the lights coming through. So, I am stopping the oscillation in the cavity, I am causing a loss in the cavity correct.

So, at this condition my pumping is going on and it is creating the population inversion. So, this one we already have learned. So, by now you should guess that what is going to happen? So, population inversion is created it is getting more and more at this point of time when I fell like way this is enough time has you know passed that I can now allow the oscillation to take place in the cavity, reduce the loss increase the gain and have output. So, what we do now? We apply a voltage to this pockel cell. So, we you know suppose this is a pockel cell here and what we do we essentially we apply a voltage. So, how much voltage generally do we put quite a high voltage. So, iii said earlier. So, it is say around 4 kilo volt. And for how long I will use it for short time duration what short time it is approximately I can say 5 micro second. So, these numbers that we using right now they are actually some practical number. So, so that is why I thought of choosing this particular number.

So, for this short duration of time this is 5 microsecond my voltage is applied. And that means, the during this period of time my pockel cell is active. Now the voltage is applied in such a way that this is capable of canceling the effect of the quarter wave plate; that means, whatever quarter wave plate have done. So, quarter wave plate has done you know at the end it has flipped the polarization of the light from horizontal to vertical that is all it has done ultimately whatever be the detail mechanism we have discussed about it. So, ultimately the affect is to flip the polarization when I apply this 4 k v voltage. Here for this pockel cell which is say a KDP. It can cancel the rotation of the linearly polarized you know the plane of polarization from vertical to horizontal again if I use an adequate voltage and in certain cases this 4 k v voltage is exactly that. So, sometimes this is called v pi by 2 so; that means, it is causing a flip of the polarization direction by 90 degree by pi by 2. So, we are out of time today. So, we will start from here in the next day and we will talk about this one little bit more and also look at other possible q switching modes ok.

Thank you very much.