Solid State Physics
Lecture 48
Mobility, Impurity Conductivity, and Fermi Surface

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Now, let us consider the concept of Mobility. What is mobility? The mobility is the magnitude of the drift velocity of a charge carrier per unit electric field. If we have; so, μ denotes the mobility, if we have a drift velocity v, its absolute value for an electric field E, then $\mu = \frac{|\vec{v}|}{E}$, that gives us the mobility of the charge carrier. The mobility is defined to be positive, that is it is directionless for carriers, both type of carriers, electrons and holes. The electric conductivity is the sum of the electron and hole contributions in the conductor. So, the conductivity $\sigma = e(n\mu_e + p\mu_h)$ So, the mobility of electrons can be given as $\mu_e = \frac{e\tau_e}{m_e}$ charge times the mean free time that is the relaxation time over the effective mass of electrons, and that for hole, mobility for hole can be given as $\mu_h = \frac{e\tau_h}{m_h}$ charge times the relaxation time for hole over the effective mass of hole. These $\tau' s$ are the relaxation times. Now, if we have impurity in the semiconductor then we have a completely different kind of a picture. If we consider silicon has 4 co-ordinations. It is a three-dimensional structure, if we have one silicon atom here then it is coordinated with one atom here, one atom here, one atom here, and one atom on this out of this plane somewhere say here. Could not draw it properly. Let us shift it a bit like this. So, all these are silicon atoms. This is the kind of arrangement silicon forms and you can see that silicon at its outermost shell has 4 electrons. Now, if we replace one of these silicon atoms with say a phosphorus atom, in place of silicon we put a phosphorus which has 5 atom, 5 electrons in the outermost shell. So, it contributes one more electron into the system. It is a donor kind of an impurity. And this donor adds electrons to the system. So, it dopes n-type. (Refer Slide Time: 04:43)

In contrast, if we add a boron here if we replace this silicon with a boron here, then what happens? Boron has three electrons at the outermost shell, therefore, it adds a hole to the system. So, the doped carrier, nature of the doped carrier becomes hole like p-type and it is an acceptor. That is the kind of system it becomes. And those are the carriers, and they govern the transport in the system and you have already learned how they form the active elements in a semiconductor device, and a device circuit, like diodes, transistors, and all. (Refer Slide Time: 05:38)

Now, let us see the Fermi surface, the band structure in reduced zone scheme, and all that. What is the reduced zone scheme? Let us; we have drawn the band structure in the context of nearly free electron model. We are going to do something similar here. Let us consider this to be the first Brillouin zone. This is the second Brillouin zone, this is the third Brillouin zone and so on. If that is the situation, then in nearly free electron model we have seen that the bands look somewhat like this, and so on. So, this part is called the extended zone scheme. And if we now plot everything within the first Brillouin zone that would be reduced zone scheme. That means, we would have this one translated here and this one translated here, we will have a band looking like this. Sorry for my drawing, but this is the idea. This one is called a reduced zone scheme. And if we repeat this reduce zone scheme on each zone that will would be called a periodic zone scheme. We are not plotting that periodic zone scheme here, but that is the idea of getting a periodic zone scheme, mostly we plot band structure using this reduced zone scheme. Now, let us consider the idea of Fermi surface. (Refer Slide Time: 08:20)

Let us consider a two-dimensional Brillouin zone because that is something we can show. The boundary equation of the zone boundary can be given as $2\vec{k} \cdot \vec{G} + \vec{G}^2 = 0$. It is satisfied if $\vec{k}$ terminates on the plane normal to the $\vec{G}$ and at the midpoint of G. So, the first Brillouin zone of a square lattice is the area enclosed by the perpendicular bisectors of $\vec{G_1}$ and the three reciprocal lattice vectors equivalent by symmetry. So, the first, if we have reciprocal lattice points somewhat like this, then these are the bisector planes, this becomes the first Brillouin zone, then comes the second neighbor that is here. So, these are the bisector planes. This gives us the second Brillouin zone here, here, here, and here. Similarly, we can obtain the third Brillouin zone by drawing another extension of this, and the Fermi surface, it will not be a surface if we consider a two-dimensional Brillouin zone. It would be surface only in the context of three-dimensional Brillouin zone. Here it would be a contour. And if we consider free electron like systems, then we will have a circular shape of that Fermi contour. So, something like this for example. Let me draw it in a different colour, and let me try to draw it a bit more consistently, so that the picture is a good one. So, it would look somewhat like this. This would be the Fermi contour. Its extension for three-dimensional Brillouin zone or three-dimensional reciprocal lattice, three-dimensional real lattice is the Fermi surface. So, what we have drawn here is not confined within the first Brillouin zone. And using this kind of a reduced zone scheme that we have discussed here, we can bring it into the first Brillouin zone by translating different parts of it into different sections of the first Brillouin zone. It will not look like a circle anymore. But that is the circular Fermi contour in essence.