Transducers For Instrumentation

Prof. Ankur Gupta
Centre for Applied Research in Electronics (CARE)
Indian Institute of Technology, Delhi

Lecture - 29

Radiation Sensors: Scintillators and Solid-State Detectors

Hello, welcome to the course Transducers for Instrumentation and we are discussing the radiation sensors or radiation detectors. In this lecture we discussed about gas filled detectors where we discussed that if we have 7a chamber and we fill the gas inside this chamber and the radiation is there. So because of that radiation the gas ionizes and the number of ions which are generated in the gas is proportional to somehow the radiation what is received by this gas and based on the applied potential difference we had three kinds of these gas filled detectors. So today we are going to discuss about the different type of detectors which is scintillation detectors and these kind of detectors work on the principle that some materials if we apply a radiation on those certain materials they emit light, the light is actually immersed out of those materials and this process or this phenomena is called fluorescence or photo phosphorescence. So, this because of this phenomena when radiation is coming to the substance and it generates a light this light can be measured by photo detectors or so. The amount of light generated is now proportional to how much radiation is received by this material.

So, this kind of process is used in these scintillation detectors. So today we are going to discuss these type of detectors. So we have scintillation detectors. So, some substances emit light when radiation falls on them. The emission process is called fluorescence. Or phosphorescence. And this light output can be used as a measure of incident radiation. This is the basic principle of these scintillation detectors. So with the material which generate this light this is coupled to some optical detector which measures how much intensity of the light is received and basically this intensity is very much proportional to intensity of the radiation received by this material. So now we have three different kinds of process by which this light is actually emitted. The first one is fluorescence where the prompt emission of light is there when we have a material, and we shine the radiation on this immediately the light actually is generated by this material which we can detect. So this is called the fluorescence. The next is the delayed fluorescence where we shine the radiation and there is a delay in the emission of this light. So that is the second one. The third one is phosphorescence where the intensity or the wavelengths of light is lower than the fluorescence case. So this is third type of process by which a material generates these light. So we have three types of process. The first one is fluorescence. In this process a prompt emission is there, prompt emission of visible radiation from a substance following its excitation.

So, this is the first process. The second process is the delayed fluorescence. The delayed emission of visible radiation from a substance following its radiation or excitation. And the third one is phosphorescence. In this the emission of longer wavelength is there compared to fluorescence and this is lighter than fluorescence. So this is the third type of process. The third type of process is the delayed fluorescence. So this is the third type of process. So this is the third type of process. So this is the third type of process. So this is the third type of process. We have three types of oscillators. So let us look at the kind of scintillators. So in this type of scintillators we have a cavity where this material is put in. For example, this is the cavity where a material is put in. This material show the property of phosphorescence or fluorescence. Now this is the cavity which is called scintillators. And the radiation comes in from outside. For example, this is the radiation coming in and it hits this material. This is gamma ray photon. So when this radiation hits this material, a light photon is generated. This is a light photon. The wavelength of this photon is in the visible range. Now this cavity is coupled to another cavity generally. This cavity is used for multiplying of this effect.

For example, one photon comes in from the left. Then this cavity is electron multiplier or simply we can call it the multiplier wherein we have a transparent section where this photon can go in. This is the region where this photon can go in. And then this photon actually generates photoelectron. Here you have a magnetic shield across it. This is the magnetic shield. And this interface is typically a photocathode. And the other side is the anode. So when this light photon comes in this cavity which is a multiplier cavity, this get bounced back by multiple electrodes and give rise to photoelectrons. And these photoelectrons which are now charged particles, these can be detected by this cathode and anode which we place in this cavity. So the number of electrons received by this cathode and anode give rise to a current in the external circuit which is a proportional measure of how many light photons are there in this multiplier cavity. And that is also proportional to the number of gamma ray photons we detected because the material is generating kind of proportional number of photons from these gamma ray photons. So this is the typical structure of a scintillator. This is a typical scintillator. So now let us discuss some important properties of a good scintillation detector.

So, the very first property of a good scintillation detector is high scintillation efficiency. The second is the light yield should be proportional to the deposited energy or the radiation. Light yield should be proportional to the deposited energy. Next is the detector material should be transparent to the wavelengths of its own emission. The detector material of its own wavelength. The next point which is important is the decay time of the induced luminescence should be shorter. should be short. And the other point is it should be possible to make them in large size and desired shape. So, in large size and desired shape. So, these are few important properties of good scintillation detector. The very first is high scintillation efficiency means when we shine the radiation on the material the proportional number of optical photons should be generated. So that is the scintillation efficiency and for this detector to work good we should have a high scintillation efficiency of that material. The next is the light yield should be proportional to the deposited energy. The number of visible photons generated should be somehow proportional to the number of gamma rays photons received by the material. So that we can make a count of how much of the radiation is being detected by the material.

So, the light yield should be proportional to the deposited energy. The third is the detector material should be transparent to the wavelength of its own emission. So we have a material when we shine the radiation on it. After accepting this radiation this material is going to generate of the visible photon the optical photon and this material should be transparent for this particular wavelength of photon. Otherwise, what will happen if it is not transparent this generated photon will be annihilated within the material itself and it will not come out which we can detect using our other circuitry. So, the detector material should be transparent to the wavelength of its own emission what it generates. So, it should be transparent to that emission. The next is the decay time of the induced luminescence should be short that is another important point, and it should be possible to make this kind of detectors in large size and desired shape so that we can have multiple applications of these kind of scintillation detectors. So, these are some important points for this. Now let us see some more important properties of good scintillation detectors. So, the refractive index should be near to that of glass means typically 1.5 or so to permit efficient coupling. With the photo multiplier tube. The next is the high density and high atomic number. And it should have good temperature stability and mechanical properties as well. It should have good resolution and ease of operation. So, these are few more important properties of these scintillation detectors. The first one is the refractive index should be close to the glass because glass is almost transparent to the visible light and if this refractive index is close to glass or 1.5 we can couple our photo multiplier tube easily with the scintillators and the photons which are visible photons they can now travel from scintillation to the photo multiplier tube without any problem. So refractive index should be close to 1.5. The good temperature stability and mechanical properties of course the scintillation detectors should be stable for any temperature change and mechanical properties should be good. It should have good resolution means if we get a little amount of radiation on the material we should have a detectable change in the output so that we can easily measure how much is the radiation being detected and ease of operation is the whole detector should be easy to operate. For example we apply a certain instrument and it directly gives the reading in how much of the radiation is being received. So this is second type of radiation detector where we have scintillation detector. Now let us discuss the third type of radiation detector which are solid state detectors where we use these semiconductor based detector for example CMOS based detectors. These CMOS devices they also we can use them to detect the detector these radiation. So let us discuss these solid-state detectors. So, in solid state detectors MOS structure or the metal oxide semiconductor structure are useful are useful because of their superior sensitivity. As well as excellent compatibility. With the existing microelectronics technology.

So, these solid state detectors are different than other gas field detectors and scintillators. In these type of detector we use semiconductor devices and one such semiconductor device is MOS device or we call metal oxide semiconductor structure which is a fairly known structure in microelectronics. This structure is useful because of their superior sensitivity it gives a very high sensitivity as well as the excellent compatibility with the existing microelectronics technology. So by the microelectronics technology we know that these MOS structure can be integrated in a very large number and also we can attach the active circuits which is used for processing the data right on the with the device itself on the same substrate. So we have a substrate where we use a MOSFET as a radiation detector. Alongside of this detector as well we can place a active circuit. So if the distances are short there is less chance of noise produced in the system. So these metal oxide semiconductor structures they give very excellent sensitivity and very good compatibility with MOS technology. So let us discuss what a MOS structure is and how it detects the radiation. So a typical MOS structure is something we have let us say we see the cross section of a MOSFET. This is let us say n-type silicon and in this we have source and drain region which is p-type in this case and we have a thick gate oxide on top of it which act like a gate for this MOSFET. So let us say this is that thick gate oxide. This terminal is source and this terminal is drain and this terminal is gate terminal. Now this is a typical MOS structure and if there is a radiation which is falling on this structure let us say the radiation is coming from somewhere.

This is radiation. What this radiation is going to do it is going to create electron hole pair in the oxide which is a insulator. This oxide which is a insulator means it does not provide conduction to charge particles, but because of this radiation there is going to be generation of electron hole pair. Let us say this positive this side negative separated to other side. So because of this radiation now this radiation is creating electron hole pair in the oxide. Now the oxide does not conduct the electricity. So whatever is the charges which are generated by this radiation they are trapped in the gate oxide. So gate oxide which was earlier neutral without the radiation when we shine the radiation it start containing a fixed amount of charge within itself. Now as we know the operation of this MOSFET structure the VT or the threshold voltage of this MOSFET is strongly dependent on the gate oxide parameters how thick the gate oxide is what material the gate oxide is whether it has certain charge trapped in it. So when there is a radiation and the charge is produced by this radiation which is trapped now in the oxide so the threshold voltage of this MOSFET changes compared to the non-radiated case. This change in the threshold voltage can be easily detected by IV measurement or the current versus voltage measurement that will show a shift in the threshold voltage and that threshold voltage shift is directly proportional to how many charge particles are there trapped in the oxide layer.

And these number of charge particles which are trapped in the oxide they are also proportional to how much dose of radiation and how much energetic the radiation is based on that radiation property these charge particles are proportional to that. So we can use this MOSFET structure as a radiation sensor where this gate oxide is the primary sensor where we are trapping the charge based on the radiation and this trapping or retrapping of the charge it changes the threshold voltage of a complete MOSFET and we measure IV characteristic and measure how much shift is there this how much shift is now proportional to the amount of radiation received by this MOSFET. So we have now the influence of radiation. MOSFET on MOS characteristic depends on both the dose and the parameters of device structure including the oxide thickness. And the effect of radiation on CV characteristic or IV characteristic can be seen. On CV characteristics is seen as a flat band voltage shift towards negative gate voltages then exposed to gamma rays or to other ionization or to other ionizing radiation. And this is due to the formation of positively charged trap centers. This happens due to the formation of positively charged trap centers in the oxide or silicon SiO2 interface. So as we discussed we use this MOSFET device for radiation detection and radiation is creating these charged particles in the oxide and because the oxide is non-conductive it is an insulator it does not allow these generated charges to escape to some other place and these charges are trapped in the gate oxide only.

Because of this trapping of these charged particles now the threshold voltage of this MOSFET is changed and to measure a threshold voltage shift in a MOSFET either we can use IV characteristic the current versus voltage characteristic or we can do a CV characteristic where we plot the capacitance gate capacitance versus the applied voltage and this CV characteristic the capacitance voltage characteristic this shows the shift in the kind of negative gate voltages and this shift is proportional to how much is the threshold voltage change. So this shift is proportional to the amount of radiation detected by the MOSFET. So this is the basic structure of solid state detectors this is how they work. Now let's see what is the effect of multiple parameters for example the oxide thickness which is the very critical parameter now for these detectors. Let's see how the thickness of these oxide changes the performance of these solid state detectors.

So the dependence on oxide thickness. So what happens in the structure the radiation induced charges a shift in the position of flat band voltage of CV curve along the voltage axis. So if we plot a typical change in the flat band voltage versus the thickness. So let's say on the Y axis I plot change in flat band voltage and on the X axis I have thickness of gate oxide typically in nanometer this is 0 and typically 100 nanometer 200 and 300 and so on and this is let's say 0.4, 0.8 like that. We can have different graphs for different radiation. For example one graph is like this. This is for typically 2 gray of radiation. The other graph can be something like this which is your 16 gray of radiation. The third graph can be like 64 gray and like this. So this is let's say 100 gray or so. So this is though the numbers are not important the trend is there when we receive the more radiation there is a more change in the flat band voltage and this can be easily detected by calculating how much charge is there in the gate oxide with respect to thickness. So if we plot the other graph where we plot the charge versus thickness and because we know the charge which is Q is equal to epsilon naught A upon B into delta B. So this is nothing but the capacitance of gate epsilon naught kA upon D.

And Q equal to C this is this full thing is C and delta V. So the Q is proportional to now all these factors and if I plot Q on the Y axis in coulomb and X axis in thickness again the axis is same as the first graph. The two gray kind of graph looks something like this and there is a significant change in the total charge which we can easily detect using electrical multimeter and some other instruments. So these are some typical trend in the gate oxide charge with respect to the thickness of the gate oxide. So we can see that there is a measurable change in the charge when we change the thickness of gate oxide and according to the radiation received which is 2 gray or 16 gray or 64 gray we get different different amount of charge trapped in the gate oxide.

Attributed to trapping of holes generated by radiation. And the electrons generated during ionization enter into the metal contact or substrate leaving behind a hole in the oxide. So these are the dependency of the change in the flat band and the charge trapped in the oxide with respect to the thickness of gate oxide which is SiO_2 and we have significant change in this flat band voltage if we change the thickness of the MOSFET and we see for 2 gray and 10 gray and 100 gray kind of radiation that this change is very noticeable. The shift, which is actually in the negative direction, so this shift is generally attributed to the trapping of holes because depending upon the shift whether it is in the right direction or the left direction in the graph we can estimate whether it is because of the electrons or because of the holes. In this particular case of this radiation measurement the shift in the graph always suggests that this is because of the trapping of holes in the oxide. So the theory is that the electrons which is generated because when the radiation hit the oxide it generates equal amount of electron and hole there.

So, the hole get trapped in the oxide and the electron which is generated this disappear either into the metal contacts we have connected to the gate or it is annihilated in the substrate and leaving behind a hole which is trapped in the oxide because of this trapping there is a shift in the threshold voltage or the change in the flat band voltage MOSFET. So today we discussed the scintillation detectors and the solid-state detectors which has superior sensitivity compared to the earlier detectors. So, this is all for today.

Thank you.