

ZERO-TEMPERATURE-GRADIENT ZERO-BIAS THERMALLY STIMULATED
CURRENT TECHNIQUE TO CHARACTERIZE DEFECTS IN SEMICONDUCTORS
OR INSULATORS

BACKGROUND OF THE INVENTION

(1) FIELD OF THE INVENTION

The present invention relates to an improved method of characterizing defects in semiconductors or insulators.

(2) DESCRIPTION OF THE PRIOR ART

Thermally stimulated current (TSC) is a well known method for the characterization of defects in semiconductors or insulators. A sample is excited either optically or electrically to fill up the defect states or traps with carriers at a low temperature, e.g. the temperature of liquid nitrogen. Then the sample is heated with the temperature increasing linearly with time. A current due to carriers being emitted from the filled defects or traps is then recorded as a function of temperature.

Usually, a bias voltage is needed as the driving force for emitting carriers during TSC measurement. However, a parasitic current which originates from the bias voltage and increases exponentially with temperature can cover up the TSC signal, especially for energetically deep defects in the band gap. Zero-bias thermally stimulated current (ZBTSC) makes use of either a built-in potential or a temperature gradient as the driving force for carriers emitted during measurement. It has been found that a parasitic current still exists for ZBTSC due to a very small temperature gradient accidentally created in the sample during ZBTSC measurement. During ZBTSC measurement, a probe is needed to contact the device under test (DUT) which is placed on the cold finger of a cryostat. A cryostat is a piece of equipment used for lowering the temperature to, for example, the temperature of liquid nitrogen. There is a temperature difference between the probe holder and the sample holder, the so-called cold finger. The temperature of the cold finger can be lowered to, for example, the temperature of liquid nitrogen. This temperature difference can produce a small temperature gradient across the DUT, resulting in a parasitic current in the ZBTSC spectrum.

Fig. 1 graphically illustrates the TSC signal at increasing temperature during ZBTSC measurement. The TSC

peaks 11 and 12 indicate defect states. 13 indicates the parasitic current due to the temperature gradient in the sample during temperature scan. The parasitic current 13 will mask the TSC peak 12.

The parasitic current during ZBTSC limits the range of ZBTSC to relatively energetically shallow defects. For example, the defects at low temperatures (11) may be found while defects at higher temperatures (12) will be masked by the parasitic current 13. Sometimes, the parasitic current can be the detection limit for even energetically ~~shallow~~ shallow defects. It is desired to find a way to provide zero-temperature-gradient ZBTSC.

A number of patents discuss the TSC technique. U.S. Patent 5,839,588 to Jantsch et al states that there is always a certain amount of leakage current present when TSC is reverse biased. This patent teaches a method of measuring change in a microwave field rather than the current measurement of TSC. U.S. Patent 5,360,267 to Ibar discusses the use of TSC to measure relaxation of especially plastics and polymers. U.S. Patent 4,496,642 to Tam et al shows a TSC method for measuring current as temperature is increased. No mention is made of leakage current or temperature gradient.

SUMMARY OF THE INVENTION

Accordingly, the primary object of the invention is to provide a process for characterizing defects in semiconductors or insulators using a zero-bias thermally stimulated current technique having a zero temperature gradient wherein parasitic current is eliminated.

A further object of the invention is to provide a novel ZBTSC apparatus that eliminates temperature gradient across a sample.

Another object of the invention is to provide a process for characterizing defects in semiconductors or insulators using a zero-bias thermally stimulated current technique wherein parasitic current is eliminated by the use of a novel ZBTSC apparatus that eliminates temperature gradient across a sample.

In accordance with the objects of the invention, a process for characterizing defects in semiconductors or insulators using a zero-bias thermally stimulated current technique wherein parasitic current is eliminated by the use of a novel ZBTSC apparatus that eliminates temperature gradient across a sample is achieved.

The novel ZBTSC apparatus comprises a cold finger on a cryostat. A sample holder is attached to the cold finger. A probe holder is attached to the cold finger. A probe is attached to the probe holder. A feedback temperature control keeps the probe and the cold finger at the same temperature. Alternatively, the sample holder may be attached to a first cold finger and the probe holder attached to a second cold finger. Feedback temperature controls for each cold finger are programed such that their temperatures are kept the same. The improved zero-bias thermally stimulated current technique of the invention comprises mounting a sample on the sample holder of the novel ZBTSC apparatus. The sample is excited at a first temperature to fill up defect traps with carriers and then heated to a second temperature higher than the first temperature wherein the heating is a linear function with respect to time. Defects are characterized by measuring current due to emission of the carriers from the defect traps as a function of temperature wherein the measuring is performed by the probe of the novel ZBTSC apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings forming a material part of this description, there is shown:

Fig. 1 is a graphical representation of a thermally stimulated current (TSC) signal at increasing temperatures during ZBTSC measurement showing parasitic current which occurs in the prior art.

Fig. 2 is a graphical representation comparing the zero-bias thermally stimulated current (ZBTSC) technique of the prior art to the zero-temperature-gradient zero-bias thermally stimulated current (ZTGZBTSC) technique of the present invention.

Figs. 3 and 4 are cross-sectional representations of the novel ZBTSC apparatus of the present invention.

Fig. 5 is a cross-sectional representation of a possible sample used in the process of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The zero-temperature-gradient zero-bias thermally stimulated current (ZTGZBTSC) technique of the present invention is used to characterize defects in semiconductors or insulators. For example, a semiconductor

device structure is fabricated to a particular point in the process and then is subjected to the ZTGZBTSC technique to characterize any defects that may have been formed within the device. This information is then used to modify process steps, as necessary.

For example, a simple sample is illustrated in Fig. 5. A gate electrode 18, which can be metal or heavily doped semiconductor, is fabricated on top of a thin film of semiconductor or insulator 19. The film of semiconductor or insulator is on top of a conductor 20 which can be a metal ~~or~~ heavily doped semiconductor substrate.

It will be understood by those skilled in the art that the example give in Fig. 5 is illustrative only. The process of the invention can be used on any device structure comprising semiconductor or insulator elements.

Now the device in Fig. 5, for example, or any other semiconductor device, is to be subjected to the zero-bias thermally stimulated current technique of the present invention in order to characterize defects formed in the process of manufacture to this point.

The sample, such as the device shown in Fig. 5, is excited either optically or electrically to fill up the defect states or traps with carriers at a low temperature, e.g. the temperature of liquid nitrogen. Then the sample is heated with the temperature increasing linearly with time. A current due to carriers being emitted from the filled defects or traps is then recorded as a function of temperature. The zero-bias thermally stimulated current technique makes use of either a built-in potential or a temperature gradient as the driving force for carriers emitted during measurement.

The zero-temperature-gradient zero-bias thermally stimulated current (ZTGZBTSC) technique of the present invention will increase both the range and the detection limit of the basic ZBTSC technique. This can be seen graphically in Fig. 2. E_c is the bottom of the conduction band and E_v is the top of the valence band.

As explained above, the undesirable temperature gradient across the sample comes from the temperature difference between the probe holder and the cold finger. The probe holder is usually at a temperature of close to room temperature, whereas the cold finger is brought from, for example, the temperature of liquid nitrogen to a temperature above room temperature. The temperature

difference between the probe holder and the cold finger can produce a temperature gradient across the sample. To solve this problem, the probe holder should have the same temperature as the cold finger. This new technique is called zero-temperature-gradient zero-bias thermally stimulated current (ZTGZBTSC) by the inventors.

To realize the ZTGZBTSC technique of the present invention, two probe holders and the sample can be mounted on the same cold finger. One embodiment of the novel ZBTSC apparatus of the present invention is illustrated in ~~Fig. 3~~ Fig. 3. Cold finger 30 is shown. The cold finger, usually made of copper, is attached to the cooling element, heater, and temperature sensor of the cryostat inside a vacuum chamber. An insulator 32, such as mica, overlies the cold finger. The sample 36 is mounted onto the cold finger by means of a conductive adhesive 34, such as silver paint. The sample 36 in this figure is a simplified device. The sample may be any device comprising semiconductors or insulators, such as, but not limited to, the device illustrated in Fig. 5. Probe holders 38 are also mounted on the cold finger, e.g. by nylon screws. Probes 40 and 42 are used as top and bottom contacts, respectively. During the temperature scanning in ZBTSC measurement, there will be one set of feedback temperature controls such that the two probes and

the cold finger will have the same temperature.

Fig. 4 illustrates a second embodiment of the novel ZBTSC apparatus of the present invention. Cold finger 30 holds the sample 36, mounted as in the first embodiment over an insulator layer 32 by means of a conductive adhesive 34. The probe holder 38 can be mounted on a second cold finger 31. There may be another second cold finger for a second probe holder 38, as shown, if two probes 40 and 42 are to be used. During the temperature scanning in ZBTSC measurement, there are two sets of feedback temperature controls (from the first and second cold fingers 30 and 31, respectively). The two sets of feedback temperature controls are programmed such that the two cold fingers will always have the same temperature.

Using the novel ZBTSC apparatus of the present invention, in either of the two preferred embodiments or any other embodiments such that the probe holders are mounted on a cold finger to achieve the same temperature as that of the sample, results in a zero temperature gradient across the sample. Elimination of the temperature difference between the probe holder and the cold finger holding the sample eliminates the parasitic current shown in Fig. 2. Thus, the process of the present invention using the novel ZBTSC

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apparatus results in an improved method of characterizing defects in semiconductors or insulators.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

What is claimed is:

Claims:

1. A method of characterizing defects in a sample comprising:

mounting said sample on a first cold finger of a cryostat;

exciting said sample at a first temperature to fill up defect traps with carriers:

heating said sample to a second temperature higher than said first temperature wherein said heating is a linear function with respect to time; and

characterizing said defects by measuring at zero bias current due to emission of said carriers from said defect traps as a function of temperature wherein said measuring is performed by a probe mounted onto a second cold finger whereby said probe and said first cold finger are at the same temperature.

2. The method according to Claim 1 wherein said sample comprises semiconductor devices comprising semiconductor or insulator layers.

3. The method according to Claim 1 wherein said first temperature is between about -197 and 0°C .

4. The method according to Claim 1 wherein said second temperature is at or above room temperature and higher than said first temperature.

5. The method according to Claim 1 wherein no bias voltage is used to force said emission of said carriers during said measuring step.
6. The method according to Claim 1 wherein said probe is attached to a probe holder mounted onto said second cold finger.
7. The method according to Claim 1 wherein a first probe contacts a top portion of said sample and wherein a second probe contacts a bottom portion of said sample and wherein said first and second probes are attached to first and second probe holders mounted on said second cold finger.
8. The method according to Claim 1 wherein said first cold finger and said second cold finger comprise a single cold finger.
9. The method according to Claim 1 wherein feedback temperature controls for each of said first cold finger and said second cold finger are programmed such that said first cold finger and said second cold finger will have the same said temperature.
10. The method according to Claim 8 wherein a feedback temperature control for said single cold finger assures that said probe and said single cold finger will have the same said temperature.

11. A method of characterizing defects in a sample in the fabrication of integrated circuits using a zero-bias thermally stimulated current technique comprising:

mounting said sample on a first cold finger of a cryostat wherein said sample comprises semiconductor or insulator materials;
exciting said sample at a first temperature to fill up defect traps with carriers;
heating said sample to a second temperature higher than said first temperature wherein said heating is a linear function with respect to time; and
characterizing said defects by measuring at zero bias current due to emission of said carriers from said defect traps as a function of temperature wherein said emission is driven by a zero-bias method and wherein said measuring is performed by a probe mounted onto a second cold finger whereby said probe and said first cold finger have the same temperature.

12. The method according to Claim 11 wherein said sample comprises semiconductor devices comprising semiconductor or insulator layers.

13. The method according to Claim 11 wherein said first temperature is between about -197 and 0°C.

14. The method according to Claim 11 wherein said second temperature is at or above room temperature and higher than said first temperature.
15. The method according to Claim 11 wherein said probe is attached to a probe holder mounted onto said second cold finger.
16. The method according to Claim 11 wherein a first probe contacts a top portion of said sample and wherein a second probe contacts a bottom portion of said sample and wherein said first and second probes are attached to first and second probe holders mounted on said second cold finger.
17. The method according to Claim 11 wherein said first cold finger and said second cold finger comprise a single cold finger.
18. The method according to Claim 11 wherein feedback temperature controls for each of said first cold finger and said second cold finger are programmed such that said first cold finger and said second cold finger will have the same said temperature.
19. The method according to Claim 18 wherein a feedback temperature control for said single cold finger assures that said probe and said

single cold finger will have the same said temperature.

20. A zero-bias thermally stimulated current apparatus comprising:

a cold finger on a cryostat;
a sample holder attached to said cold finger
a probe holder attached to said cold finger;
a probe attached to said probe holder; and
a feedback temperature control whereby said probe and said cold finger are kept at the same temperature.

21. The zero-bias thermally stimulated current apparatus according to Claim 20 further comprising:

a second probe holder attached to said cold finger;
and
a second probe attached to said second probe holder.

22. A method of characterizing defects in a sample using said zero-bias thermally stimulated current apparatus of Claim 20 comprising:

mounting said sample on a sample holder wherein said sample comprises semiconductor or insulator material;
exciting said sample at a first temperature to fill up defect traps with carriers;

heating said sample to a second temperature higher than said first temperature wherein said heating is a linear function with respect to time; and
characterizing said defects by measuring at zero bias current due to emission of said carriers from said defect traps as a function of temperature wherein said measuring is performed by a probe.

23. A zero-bias thermally stimulated current apparatus comprising:

- a first cold finger on a cryostat;
- a sample holder attached to said first cold finger;
- a first feedback temperature control for said first cold finger;
- a probe holder attached to a second cold finger;
- a probe attached to said probe holder; and
- a second feedback temperature control for said second cold finger wherein said first and second feedback temperature controls are programmed such that said probe, said second cold finger, and said first cold finger are kept at the same temperature.

24. The zero-bias thermally stimulated current apparatus according to Claim 23 further comprising:

- a second probe holder attached to said second cold finger; and
- a second probe attached to said second probe holder.

25. A method of characterizing defects in a sample using said zero-bias thermally stimulated current apparatus of Claim 23 comprising:

mounting said sample on a sample holder wherein said sample comprises semiconductor or insulator material;

exciting said sample at a first temperature to fill up defect traps with carriers;

heating said sample to a second temperature higher than said first temperature wherein said heating is a linear function with respect to time; and

characterizing said defects by measuring at zero bias current due to emission of said carriers from said defect traps as a function of temperature wherein said measuring is performed by a probe.