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Estimation of Insulating Materials for Semiconductor Power Device using DC Current Integrated Charge Measurement

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Abstract

A principle of “DC current integrated charge measurement method”, which is usually called as “Q(t) method” for simplicity, and some typical measurement results obtained using the Q(t) method are introduced in this paper. The Q(t) method is used for estimation of insulating properties of materials at various temperature under various DC electric field, while the measurement system for it is simple and not so expensive. Furthermore, since the method is applicable to variously shaped insulating materials, it is useful for various electric and electronic devices. Recently, some semiconductor power devices using some newly developed semiconductor like SiC or GaN, which work at high temperature under high electric stress, are developed for actual use driver circuits of electric vehicles and trains. To draw their authentic power at the higher temperature under the higher electric stress, it is necessary to improve the insulating materials to show a good insulating performance under such severe condition. Therefore, estimation of the insulating properties under such condition is also important. The Q(t) method seems to be a suitable technique to estimate them. In this paper, some estimation results on some commercially available power devices are reported to show the effectivity of the method.

Keywords: Semiconductor power device • DC current integrated charge measurement • Estimation of insulating property • DC voltage

Introduction

In recent years, it is one of the most important problems to be resolved is a prevention of global warming progresses. For semiconductor power devices, an energy-saving and a high efficiency performance are also required to reduce a greenhouse gas emission. Some power devices using a newly developed semiconductor like SiC or GaN are expected to improve them because they are available under severer conditions at the higher temperature of more than 200˚C under the higher voltage of more than 10 kV rather than those for the conventional Si based semiconductors, and consequently the developed devices can be used without huge cooling system. However, to draw their authentic potentials under the above-mentioned conditions, it is necessary to improve the insulating performance of materials surrounding the semiconductors under such severer conditions. In general, since the insulating materials usually have a low thermal conductivity, it is necessary to reduce the thickness of the materials. At this moment, since insulating materials have not been used under such severer conditions, there is no adequate method to estimate the insulating characteristics under such conditions. Therefore, it is necessary to develop an adequate test method to estimate the insulating performance under such severe conditions. To estimate the insulating property in materials, a space charge accumulation is expected to one of parameters that shows the condition of the insulating ability. When the space charge accumulates in the insulating material by applying the dc high voltage to the insulating materials, the space charge is often observed in them, and sometimes a breakdown occurs in the materials after a large amount of space charge accumulation is observed [1]. Therefore, the space charge measurement may be used to evaluate the degradation of insulating materials. A PEA (pulsed electro-acoustic) method is a popular space charge distribution measurement technique for the evaluation [2,3]. However, the PEA method is usually applied to thin film shape samples, and it is difficult to evaluate actual insulating materials with complicated shapes in electronic devices. Therefore, a direct current integrated charge method (DCIC-Q(t) or simply “Q(t)”) method is expected to be applied to the evaluation of the charge accumulated insulating layer of the electric device [4,5]. In this report, a principle of the Q(t) method is introduced at first, then some typical results are also introduced. In this research work, we tried to evaluate the insulation layer of IGBT (insulated bipolar transistor) module using Q(t) method. In addition, we examined whether it is possible to predict the failure of the power module using the Q(t) method.

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Measurement Principle and Typical Results

Conventional current measurement to estimate insulating property

Insulating materials in semiconductor power devices usually have the structure shown in **Figure 1**. For the high temperature usage of them, ceramic materials have been usually used. However, due to some demerit of the ceramic materials like its brittleness, heavy weight and poor workability, epoxy based composite materials with ceramic filler becomes preferable to be used for it. The epoxy based composite materials shows a good workability with light weight. However, the materials usually show a poor insulating property especially at high temperature, while the epoxy base is a good insulating material. Therefore, many ideas to improve the insulating property have been proposed. However, it is important to show the developed materials according to the proposed ideas is available under the designed conditions.

Insulating materials are usually evaluated by a measurement of “conduction current” using the circuit shown in **Figure 2** [6]. In this measurement, when a voltage V_0 is applied to a sample, a relatively large “instantaneous current” I_0 [A] (=V_0/R) is measured at first, as shown in **Figure 3** [6]. After that, it gradually decreases with time, and it finally becomes steady small current Id after a very long time. The steady current is called “dc leakage current”. A current density J [A/m^2] (a current per unit area) of this dc leakage current is proportional to an electric field E [V/m] (applied voltage per thickness of the material) when the applied voltage is relatively low. The proportional relation is called “Ohm’s law” and the proportional coefficient is called “conductivity” [S/m]. For the insulating material, this range of electric field where Ohm’s law is applicable is defined as “low electric field”. However, when the applied voltage is increased, the current density increases with deviating from Ohm’s law. This range of electric field where the current density deviates from Ohm’s law is generally recognized as “high electric field” as shown in **Figure 4** [6]. The threshold between the ranges

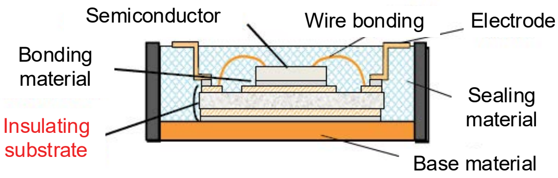


Figure 1. General structure of semiconductor power.

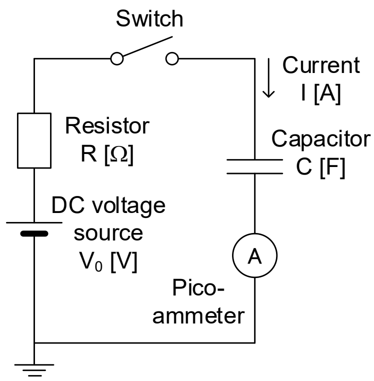


Figure 2. Measurement circuit for conduction current in dielectric materials [6].

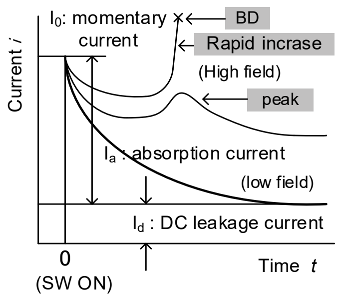


Figure 3. Various types of measured current [6].

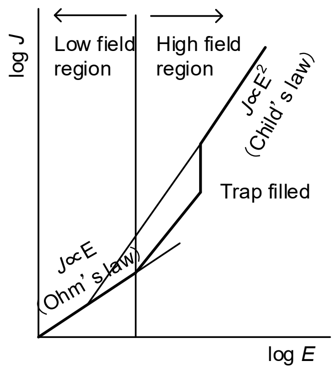


Figure 4. Relationship between conduction current (J) and applied electric field (E).

of low and high electric fields depends on the materials. One of the reasons why the deviation from Ohm's law under high electric field is thought that so called "space charge" accumulates in the material. Anyway, the insulating materials should be used in the range of "low electric field", and the E-J characteristic is necessary to be measured to estimate the insulating material. However, it takes a very long time to observe the steady current and it is hard to judge when the current reaches the steady state.

Principle of Q(t) method

Figure 5 shows schematic diagrams of a Q(t) measurement circuit (top) and a typical measured result (bottom) obtained using it [7]. In the circuit shown in **Figure 5**, an integral current is observed using a capacitor connected in series to the circuit by measuring time dependent voltage of the capacitor. As shown in the typical result of **Figure 5**, a rapid increase of the Q_0 (initial charge) is observed in Q(t) measurement. This value of Q_0 is an induced charge amount on the surface of the sample, and it is proportional to the applied voltage Vdc and the capacitance of the sample C. After the observation of the Q_0, Q(t) gradually increases with time progress. Figure 6 shows a schematic model of the typical time dependence of the current I(t) [7]. As shown in **Figure 6**, when the charge is not accumulated in the bulk of the sample in the range of the "low electric field", the current I(t) (dashed line) quickly decreases, and it soon achieve a steady state. The steady state current is called as the leakage current. In this case, the integral of the current during the "volt on" time is much smaller than Q_0, the Q(t) observed after Q_0 seems to be flat with the time progress as shown in Fig. 5 (dashed line). On the other hand, when the charge is accumulated in the bulk of the sample in the range of the "high electric field", the current I(t) gradually decreases with the time progress as shown in **Figure 6** (solid line). The transient current between the initial and the steady states is called as an "absorption current". Since the integral amount of the absorption current during the "volt on" (hatched area) is sometimes as large as the Q_0. In this case, the Q(t)after the observation of Q_0 increases obviously as shown in **Figure 5** (solid line), then it becomes a line with a certain slope which is equal to the leakage current. As shown in **Figure 5**, we can easily distinguish the Q(t)property in the range of "high electric field" from that in the range of "low electric field".

Furthermore, it is convenient to estimate the Q(t)property using the following an "amount charge ratio", which is defined as Q (tend)/Q_0, where the "tend" is the voltage application time; t1 in **Figure 5**. Since the accumulated charge Q_0 by the initial charging current is much larger than that by the absorption and leakage currents, the increase of Q(t) after the Q_0 is small, and the value at the end of measurement Q(tend) is close to Q_0, and it means that the

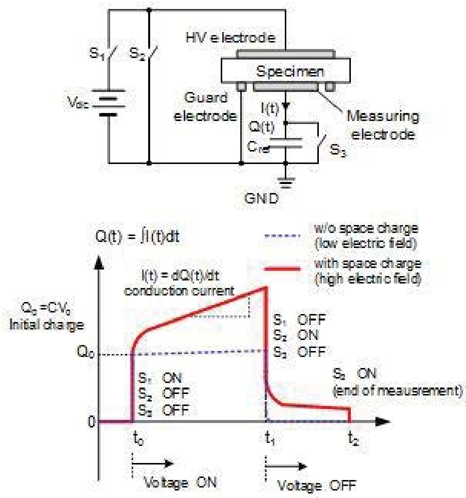


Figure 5. Measurement circuit and typical example of observed result for Q(t) method [7].

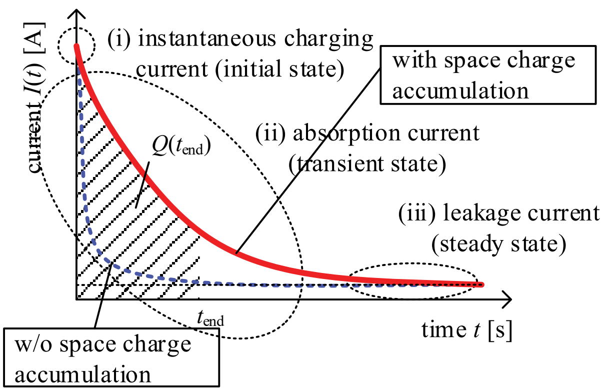


Figure 6. Typical model of time dependent current I(t) [7].

amount charge ratio Q(tend) / Q_0 is usually close to "one". In other words, while the Q(tend) / Q_0 is close to "one" under a certain condition for a material, the condition is in range of "low electric field" for the material. On the other hand, when a space charge accumulates in the sample in the range of "high electric field", the absorption and the leakage currents are not so small, and sometimes the amount charge ratio of more than "one" is observed during the measurement. Takada, et al., showed that the value of "two" in the amount charge ratio means the condition that the bulk of the sample is fully repleted by the injected charge, and more than "two" means the condition that the amount of the injected charge into the bulk is equal to the ejected charge from the bulk [8]. In such condition with the value of two or more, the material cannot be treated as an insulating material anymore. Therefore, by calculating the ratio for the obtained Q(t) characteristics, we can estimate whether the charge accumulated in the bulk of the sample or not.

Typical Measurement Result in Insulating Materials for Cable.

To introduce a typical measurement result, **Figure 7** shows a time dependence of Q(t) obtained by applying a dc escalating stepwise voltage from 300 V to 18 kV to an insulating material of a commercially available coaxial cable (5D-2V, 112 cm long with 1.4 and 5.5 mm are inner and outer conductor diameter) at room temperature [9]. Each voltage is applied for 300 seconds and then the cable was short circuited for 120 seconds in each measurement. As shown in **Figure 7**, no increase in Q(t) with increasing time was observed until the applied voltage exceeded 10 kV. However, an increase in Q(t) was observed when the applied voltage was increased to 12 kV or above. Figure 8 shows the dependence of the amount change ratio Q(tend)/Q0 on the applied dc voltage. In this case, Q_0 and Q(tend) are the values of Q(t)s observed at t = 4 and 300 seconds, respectively [9]. As shown in **Figure 7**, the ratio in the vertical axis remained constant and close to 1 when the applied voltages were below 10 kV. The ratio increased with increasing applied voltage when the applied voltage exceeded 10 kV. For example, the ratio was 1.1 when Vdc = 12 kV, and it was 1.3 when Vdc = 14 kV. Furthermore, Q(t)rapidly increase increased when Vdc exceeded 18 kV resulting in the breakdown of the cable. Judging from this result, it is easy to understand that this cable is available below 10 kV or less.

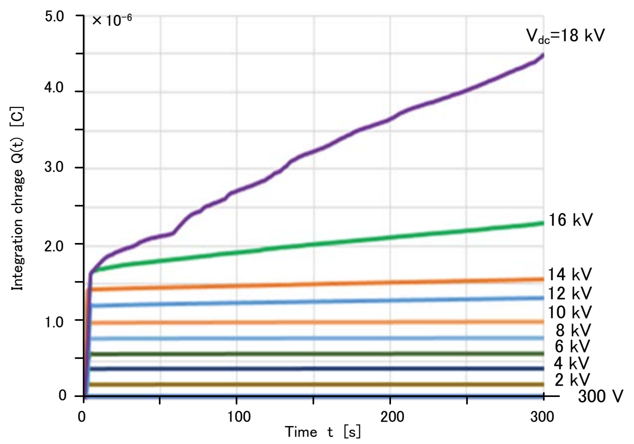


Figure 7. Typical measurement result of time dependent Q(t) in cable insulating material [9].

IGBT Samples and Experimental Procedure

Samples

Two kinds of commercially available IGBT modules were used as the measurement samples to show the effectiveness of the Q(t) method [7]. Here, they are described as IGBT-A and IGBT-B. Since the details of the structure of them were not revealed, only some data from the commercial catalogues are described in Table 1 to show the differences between them. Furthermore, IGBT-A was a used one as a part of motor driving circuit for several years, and IGBT-B was a brand-new one.

For the next experiment to study breakdown and degradation characteristics, other new commercially available IGBT module was also prepared, and we call it as IGBT-C in this paper [10]. Table II shows typical properties of this sample. In the case of IGBT-C, two annealed samples were also prepared to study a degradation effect of the sample. One of them were annealed at 180˚C for 12 hours in air atmosphere, and another was also annealed with applying a positive rectangular voltage during the annealing. The applied rectangular voltage is 3 kV in height with an application frequency of 500 Hz. The duty ratio of the rectangular voltage was 50 %. The annealing condition was the same to the above-mentioned annealing condition. Here, the above annealed samples are described as IGBT-CH and IGBT-CHV in this report, respectively.

Measurement Procedure

To measure the Q(t), a commercially available Q(t) meter (A&D Co., AD-9832A) was used. Figure 9 shows the measurement circuit to measure the time dependence of Q(t) in the IGBT modules [7]. In this measurement, all terminals of the IGBT were connected to apply voltage to the module insulating layer equipotential as shown in **Figure 1**. The module was set on a grounded plate heater to increase temperature of the module, and Q(t) was measured by applying a various voltage to the terminal at various temperature from RT (room temperature; ca. 25˚C) to 180˚C. While the structure of the sample is unknown, we assumed it may be close to the model depicted in **Figure 1**. Therefore, by applying a voltage to the terminal, we assumed that the voltage is mainly apply to the insulating substrate. As shown in **Figure 9**, since the measurement system has a "ZigBee" wireless transmitter, it enables to measure the Q(t) by floating the whole system from the ground potential if the system is connected in a high voltage side of the measurement circuit. However, in this experiment, the system is connected in the grounded side circuit as shown in **Figure 9**.

In this Q(t)measurement, to measure the time dependent Q(t) characteristics under various voltage, an escalating stepwise voltage is sequentially applied to the sample. **Figure 10** shows a schematic diagram of a voltage application sequence for measuring Q(t) in the samples [7]. In this experiment, a dc voltage was applied to the sample and the voltage of the detective capacitance was measured for 3 min, then the measured voltage data are wirelessly transmitted

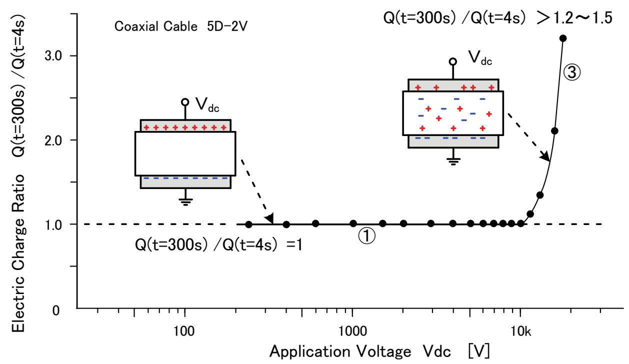


Figure 8. Typical dependence of amount charge ratio of Q(t) on the applied dc voltage to an insulating material of a coaxial cable [9].

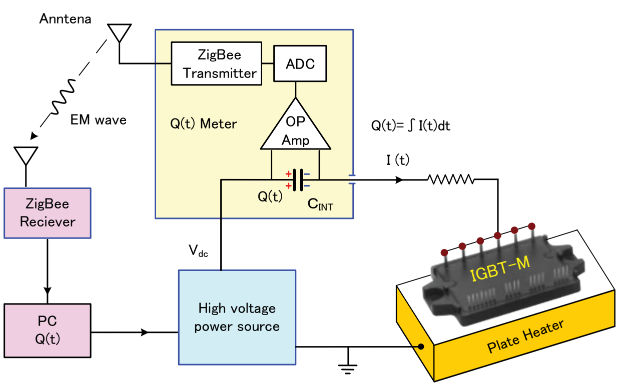


Figure 9. Schematic model of Q(t) measurement circuit for diode bridge and IGBT modules [7].

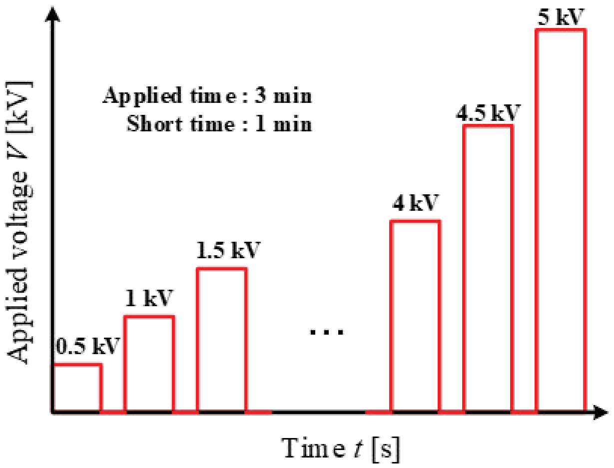


Figure 10. Typical sequence of DC voltage application for Q(t) measurement [7].

to a computer continuously, then the dc voltage is removed, and the Q(t)also measured for 1 min continuously. After that, the escalated voltage is applied to the sample as the next step as shown in **Figure 10**. Only when the breakdown in the module was observed, the applied voltage step was increased up to 5 kV for IGBT-A and -B or 10 kV for IGBT-C. The details of the measurement system and the principle are described elsewhere [4].

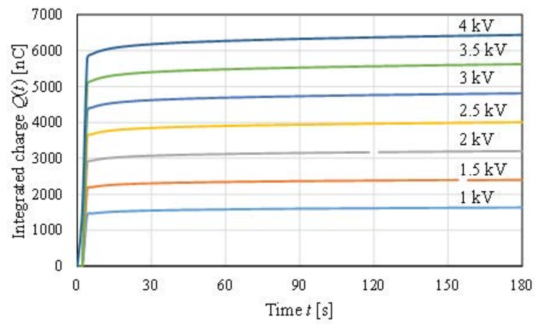
In these experiments, the reproducibility of the measurements for the brand-new packages were confirmed by measuring at least twice using the new sample for each measurement. Since the obtained results were mostly similar to each other, one result of them is introduced here. In the case of the used sample, since it was hard to get the sample with similar condition, the reproducibility was confirmed by measuring the same sample twice. In this case, almost the same results were also obtained, and the fist measurement result is introduced here.

Results and Discussion

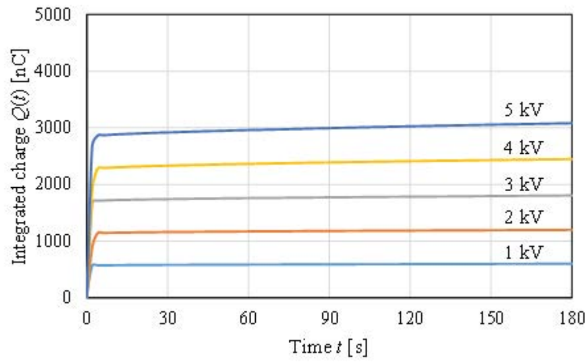
Typical Results and Evaluation of IGBT Module

Figures 11a and 11b show typical time dependences of measured Q(t)at RT (ca. 25˚C in IGBT-A and -B, respectively [10]. As shown in both results, the measured Q(t)increased rapidly at first, then it became gradually increase with increase of the voltage application time under all applied voltages. The first rapid increase of Q(t) is due to an "initial charging current", and a value of the initial rise Q_0 is described as the product of the capacitance of the sample Cs and the applied voltage Vdc ($Q_0 = C_sVd_c$) [4]. The gradual increase of Q(t)following Q0 is caused of absorption and leakage currents as mentioned above. In these measurements, the voltage application time is 3 min (180 seconds), and Q (tend) is described as Q 180 in this paper. Judging from the values of Q180 of IGBT-A and -B shown in **Figure 9a and 9b** are both close to their values of Q_0. It means that the ratios of Q 180/ Q_0 are close to "one" in both samples. It means that both samples are in the range of "low electric field" under these measurement conditions.

On the other hand, the insulating properties at 80˚C are different from those at RT. **Figures 12a and 12b** show typical results of time dependent Q(t) measurement results at 80˚C in IGBT-A and IGBT-B, respectively [10]. Please note that the voltage increment steps and maximum voltage for the Q(t) measurements in IGBT-A are different from the sequence shown in **Figure 8** because the ratio Q_{180}/Q_0 in it exceeded the value of "two" even under the applied voltage of 500 V at 80˚C. The time dependent Q(t) in GPIB-B after Q_0 showed a very gradual increase even under 5 kV as shown in **Figure 12a**, while that in IGBT-A increased with a certain slope under each voltage as shown in **Figure 12b**. The results suggested that the IGBT-B is available at 80˚C with a relatively healthy insulating condition, while the IGBT-A is not available at 80˚C even under the voltage of 0.5 kV or less. **Figures 13** shows the dependence

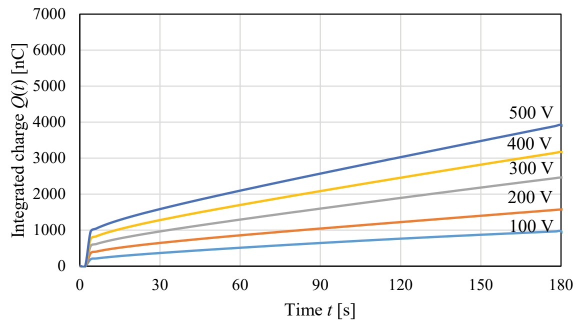


(a) IGBT-A



(b) IGBT-B

Figure 11. Time dependence of Q(t) at RT (ca. 25˚C) under various DC voltage [10].



(a) IGBT-A

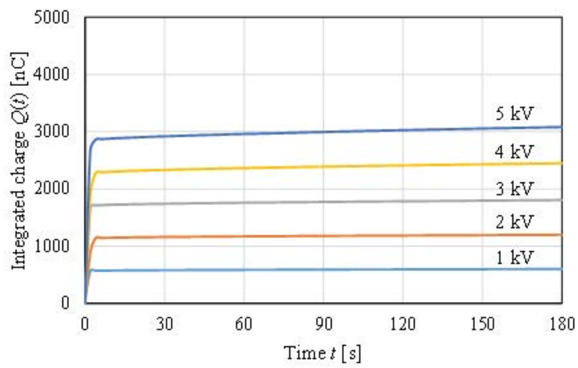


Figure 12. Time dependence of Q(t) at 80˚C under various DC voltage [10].

of the amount charge ratio Q_{180}/Q_0 on measurement temperature in IGBT-A and -B [10]. As shown in **Figure 13**, since most data at each temperature are overlapped, any obvious difference among the applied voltage is not observed, and it can be said that the dependence of the applied voltage in both samples are not significant. However, the temperature dependence of the ratio is clearly observed. For example, the ratio in IGBT-A increased around 60˚C or more even under the applied voltage of less than 0.5 kV, while the "junction temperature" and the collector-emitter voltage" were 100˚C and 600 V, respectively, on the catalogue described in **Table 1**. On the other hand, it seemed that the Q_{180}/Q_0 increased at 120˚C or more even under the applied voltage of 5 kV, and the junction temperature and the collector-emitter voltage were 150˚C and 600 V on the catalogue described in **Table 1**. The insulating layer in IGBT-A might have degraded for the long usage as the motor driver. On the other hand, the insulating layer in IGBT-B seemed to keep its soundness at 100˚C even under 1 kV or more. Anyway, by observing the characteristics of the ratio, we can estimate the insulating condition of the IGBT modules.

Evaluation of Degraded IGBT Module

Figure 14 shows temperature dependent Q_{180}/Q_0 ratios in IGBT-C, CH and CHV, which are IGBT modules of the brand new, the annealed and the annealed with the electric stress, respectively [10]. In these measurements, since it was hard to observe the Q(t) at 180˚C under 4 kV or more because the observed voltages of detecting capacitor under the conditions were too large over the range of the measurement, the values under 3 kV or less were depicted in this figure. Judging from the result shown in **Figure 14**, it seems to be hard to distinguish among them using the Q_{180}/Q_0 ratios. However, the difference was observed obviously in the values of Q_0. Figure 15 shows the dependence of Q_0 on the applied dc voltage at various temperature in IGBT-C, CH and CHV [10]. While there is no difference between IGBT-C and CH under all measurement conditions, only the Q_0 of IGBT-CHV shows a large value

Table 1. Properties of IGBT-A and B.

	IGBT-A (Company A, used)	IGBT-B (Company B, new)
Collector-Emitter voltage	600 V	600 V
Junction temperature	100˚C	150˚C

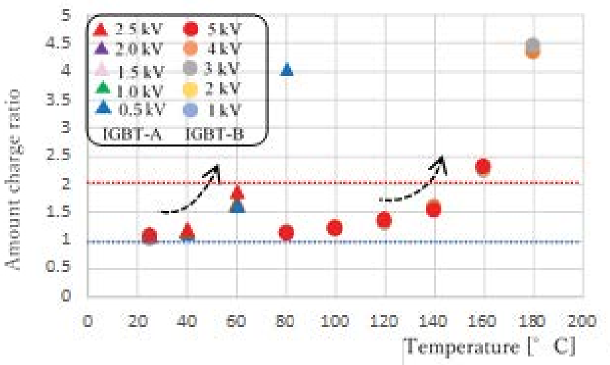


Figure 13. Temperature dependence of amount charge ratio Q_{180}/Q_0 in IGBT-A and IGBT-B under various DC voltage [10].

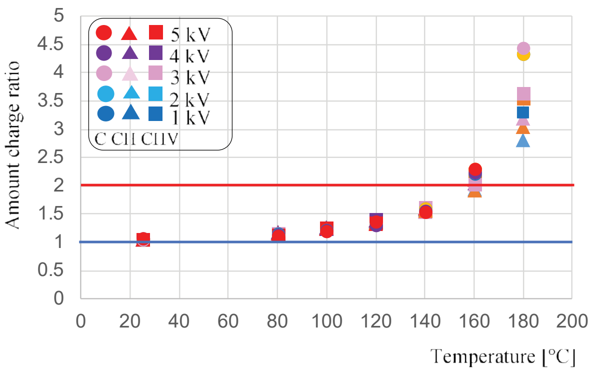


Figure 14. Temperature dependence of amount charge ratio Q_{180}/Q_0 in IGBT-C, CH and CHV under various DC voltage [10].

at high temperature at 140˚C or more under the applied voltage of 4 kV as shown in **Figure 15**. It suggested that the apparent permittivity of the insulating layer of IGBT-CHV was changed by the annealing with the electric stress of the rectangular voltage, and the insulating layer may be degraded by the treatment. Anyway, from above mentioned treatment, it was hard to estimate the degradation affected by the treatment, it can be said that the IGBT may not be available at 160˚C or more as shown in **Figure 14**, and it is interested that the temperature is close to the "junction temperature" in the **Table 2**.

Observation of Q (t) under high dc stress until breakdown

To study the property of the Q(t) measurement result near the electric breakdown, the stepwise dc voltage was applied to the IGBT-C until breakdown with a raising voltage step of 0.5 kV each. **Figure 16** shows the time dependent

Table 2. Properties of IGBT-C.

(IGBT-C: Company B, new)	
Collector-Emitter voltage	600 V
Collector current (continuous)	50 A
Collector power dissipation (1device)	200 W
Junction temperature	150˚C

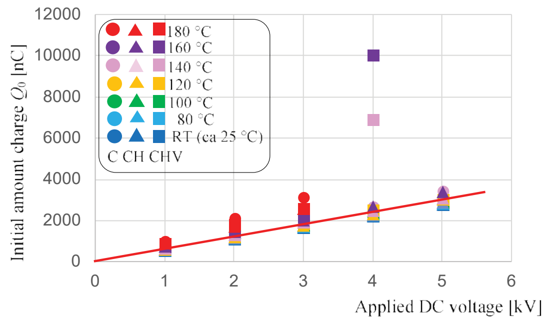


Figure 15. Dependence of initial amount of charge Q_0 on applied dc voltage in IGBT-C, CH and CHV at various temperatures [10].

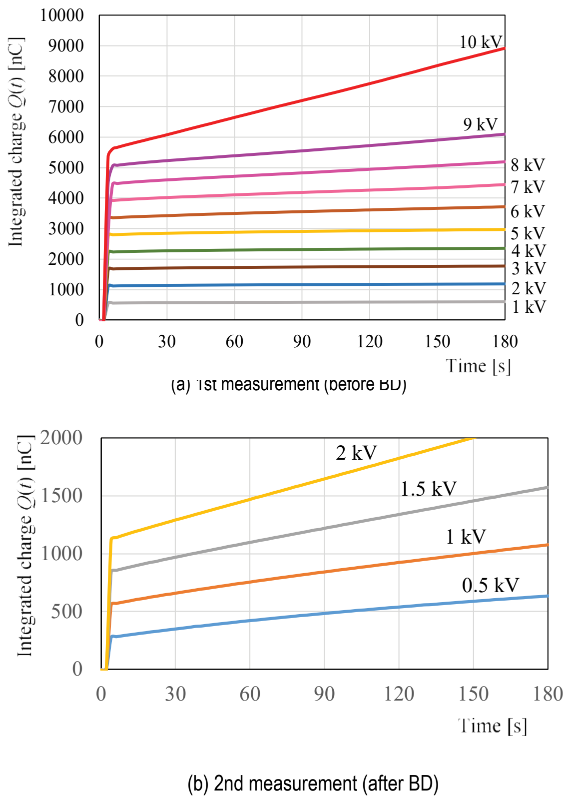


Figure 16. Time dependence of Q(t) in the (a) 1st and (b) 2nd measurements at RT (ca. 25 °C) under various DC voltage [10].

Q(t) at RT in IGBT-C [10]. **Figures 16a and 16b** show the results obtained in the (a) first and (b) second measurements for the same sample, respectively. In the case of **Figure16a**, only the results under the voltage steps with 1 kV step each are described to show the result clearly. In the first measurement, a new sample was measured, and the measurement was stopped when the applied voltage was down automatically by the high voltage souse. Since the power supply has an automatic shout-off function, the voltage is removed automatically when an overcurrent is detected. After the detection of the overcurrent, circuit is shortened, then the same measurement was conducted on the same sample as the second measurement. As shown in **Figure 16a**, the increase of Q(t) after the Q_0 was small when the voltage of 5 kV or less was applied to the sample. In this sample, the voltage was automatically down just after the voltage of 10.5 kV was applied, and a light emission was observed visually at that time. On the other hand, in the second measurement as shown in **Figure 16b**, the Q(t) after Q_0 seemed to increase with time even under the dc voltage of 0.5 kV, and it was automatically down when the 2.5 kV was applied to the sample. **Figure 17** shows the dependence of the amount charge ratio Q_{180}/Q_0 on the applied voltage in the 1st and 2nd measurements [10]. As shown in **Figure 17**, it was clear that the ratio in the 1st measurement gradually increased over 5 kV, then it became rapid increase over 9 kV. On the other hand, the ratio exceeds value of "two" even under 0.5 kV. Judging from the results of the 2nd measurement, the insulation layer must be broken in the 1st measurement process. Actually, a "black spot" was observed visually on the circuit of the module after the 1st measurement. From the above-mentioned results, the rapid increase of the ratio may be a prebreakdown phenomenon. Therefore, by measuring the Q(t) characteristics for a used module, it can be estimated that the degradation of the sample.

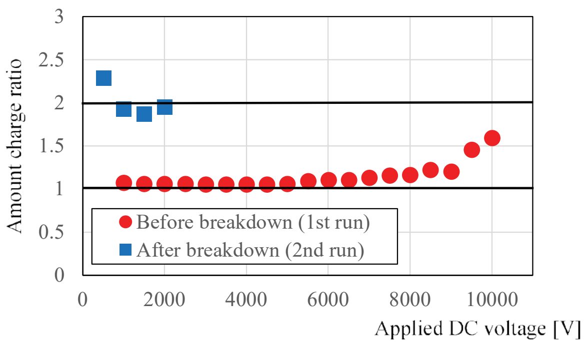


Figure 17. Time dependence of amount charge ratio Q_{180}/Q_0 in IGBT-C under various DC voltage raising until breakdown [10].

Conclusion

The direct current integral charge (Q(t)) method was applied to estimate the insulating layers used in IGBT modules. Comparing the observed Q(t) characteristics in a brand new and a used IGBT modules, it seems to be possible to distinguish which has better insulating properties. Especially temperature dependence of the amount charge ratio Q_{180}/Q_0 seems to be effective factor to evaluate the insulation properties in the actual IGBT module. Furthermore, the annealed IGBT was measured using the Q(t) method, and it is suggested that the anneal with high voltage application may degrade the insulating material in the module. In the observation of the amount of charge ratio by applying the stepwise-increasing dc voltage to the IGBT, a rapid increase of the ratio was observed, and it seems to show a prebreakdown phenomenon. Therefore, the test may be available to estimate the breakdown strength of the insulating material for the IGBT module.

As mentioned above, the Q(t) method is expected to be applied to estimate the insulating material of semiconductor power devices, and it is useful to develop and/or monitor the power devices.

References

1. Kohei, Matsui, Yasuhiro Tanaka, Toshikatsu Takada, Fukao Tadashi, Fukunaga Kaori, and et al. "Space Charge Behavior in Low-density Polyethylene at Pre-breakdown". *IEEE Trans. Dielectr. Electr. Insul* 12 (2005): 406-415.
2. Y, Li, and Toshikatsu Takada. "Progress in Space Charge Measurement of Solid Insulating Materials in Japan". *IEEE Electr. Insul. Mag* 6(1994):16-28.
3. Toshikatsu, Takada. "Acoustic and Optical Methods for Measuring Electric Charge Distribution in Dielectrics ", *IEEE Trans. on DEI* 6(1999): 519-547.
4. Toshikatsu Takada, T Fujitomi, T Mori, T Iwata and Yasuhiro Tanaka, et al. "New Diagnostic Method of Electrical Insulation Properties based on Current Integration". *IEEE Trans. DEI* 24 (2017): 2549-2558.
5. Weiwang, Wang, Keita Sonoda, Syugo Yoshida, Toshikatsu Takada, and Yasuhiro Tanaka, et al. "Current Integrated Technique for Insulation Diagnosis of Water-Tree Degraded Cable". *IEEE Trans. DEI* 25(2018): 94-101.
6. Toshikatsu, Tanaka, and Takahiro Imai. "Advance Nanodielectrics-Fundamentals and Applications", Pan Stanford Publishing (2017): 210-212.
7. Maimi, Mima, Daiki Hanazawa, Norio Hijikata, Hiroaki Miyake, and Toshikatsu Takada, et al. "Electric Charge Accumulation Properties in Packaged Insulation Layer of Power Electronic Devises by using Direct Current Integrated Charge Method". *IEEJ Trans.FM* 139(2019): 197-204.
8. Y. Sekiguchi, Toshikatsu Takada and Yasuhiro Tanaka. "Classification of Q(t) Profiles to Induced Electrode Charge, Accumulated Charge and Leakage Current Charge", *IEEJ Trans. FM* 141(2021): 245-251.
9. Toshikatsu, Takada, Toshiyuki Fujitomi, Takuma Mori, Hiroaki Miyake, and Yasuhiro Tanaka, et al. "New Diagnostic Method of Electrical Insulation Properties based on Current Integration". *IEEE Trans. Dielec Electic Insulation* 24(2017): 2549-2558.
10. Yasuhiro, Tanaka, D Hanazawa, Kimio Hijikata, Hiroaki Miyake, and Toshikatsu Takada. "Current Integrated Charge Measurement Evaluation of Insulation Layer for Power Module using DC Current Integrated Charge Measurement", *Proc. 2020 IEEE 3rd ICD* (2020): 459-462.

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