Control of Magnetic Field for Sustainment of Ion Production and Uniform Ion Flux to Substrate in Neutral Loop Discharge Plasma

Takuhei Yoshida  Student Member  (Hokkaido University)
Yohei Sakurai  Student Member  (Hokkaido University)
Hirotake Sugawara  Senior Member  (Hokkaido University)
Akihiro Murayama  Non-member  (Hokkaido University)

**Keywords**: NLD plasma, Monte Carlo method, ion production, uniform etching, separatrix

1. **Introduction**

Neutral loop discharge (NLD) plasma is a type of inductively coupled plasma used for dry etching. Its characteristic feature is that a magnetically neutral ring called neutral loop (NL) at which the magnetic fields induced by three coaxial coils surrounding the plasma chamber cancel each other (Fig. 1). The plasma is generated along the NL and the separatrix, which is the boundary dividing the plasma space into four regions and along which the magnetic field lines run. We can obtain high plasma densities at low gas pressures through this property. On the other hand, this property causes enhancement of etching rate around the position at which the separatrix crosses the substrate (the foot of separatrix).

We presented a control method of coil currents that the foot of separatrix sweeps over the substrate and the NL moves within a short distance from the RF antenna. By this operation, we expect that uniform processing of the substrate and suppression of the decoupling between the NLD plasma and the RF antenna. We simulated the electron and ion motions in the NLD plasma under the proposed control using a Monte Carlo method and analyzed the distributions of ion production and flux to substrate. Moreover, we attempted to make the ion flux to the substrate uniform by superposing the latter distributions weighted by the passage time of the foot of separatrix on the substrate.

2. **Results**

Analysis of the distribution of CF$_3^+$ ion production in CF$_4$ NLD plasma at 5 mTorr revealed the following points. Two opposite functions worked simultaneously in the operation of the position of the NL: the suppression of ionization by decrease in electric field strength and the promotion of ionization by relaxing the gradient of magnetic field. Ion production was more sensitive to the gradient of magnetic field than the electric field strength. Therefore, it is expected that the coupling between the NLD plasma and the RF antenna can be sustained under the proposed control easily.

Analysis of ion flux to substrate (Fig. 2) and uniformity evaluation of the distribution of ion flux revealed the following points. We obtained a uniform ion flux to substrate in a radius range of $r = 0–15.0$ cm with $\sigma/m = 2.7\%$ (m: the average, $\sigma$: the standard deviation) by superposing the flux distributions weighted by the passage time of the foot of separatrix on the substrate (Fig. 3(a)). In case the radius range was $r = 5–15$ cm, we obtained a high ion flux uniformity $\sigma/m = 1.1\%$ (Fig. 3(b)). Moreover, we obtained $\sigma/m = 0.25\%$ (Fig. 3(c)) for the case of $r = 4.0–14.0$ cm.

For utilizing this characteristics, we proposed a method of multi-wafer processing by arranging several substrates within the uniformed radius range (Fig. 4).
Investigation of Partial Discharge Characteristics Induced by X-ray Irradiation in Artificial Cavity in Epoxy Resin

Masakazu Higashiyama Member (TOSHIBA Industrial Products Manufacturing Co., masakazu.hgs@toshiba.co.jp)
Hajime Takada Student Member (Kyushu Institute of Technology, i349529h@tobata.isc.kyutech.ac.jp)
Masayuki Hayashi Student Member (Kyushu Institute of Technology, j349543m@tobata.isc.kyutech.ac.jp)
Masahiro Kozako Member (Kyushu Institute of Technology, kozako@ele.kyutech.ac.jp)
Masayuki Hikita Member (Kyushu Institute of Technology, hikita@ele.kyutech.ac.jp)
Shuhei Nakamura Member (Mie University, sn@elec.mie-u.ac.jp)
Tokihiro Umemura Member (Mie University, hiro.umemura@crc.mie-u.ac.jp)
Yusuke Nakamura Member (TOSHIBA Co., yusuke2.nakamura@dx.toshiba.co.jp)
Tatsuya Hirose Member (TOSHIBA Co., tatsuya.hirose@toshiba.co.jp)

Keywords: cast resin transformer; partial discharge; void size; charge; epoxy resin; X-ray irradiation

We investigate the relation between the void size and apparent charge of partial discharge (PD) occurring in a model simulating the insulation system of cast resin transformer. It is also important to determine necessary PD detection sensitivity of PD test in a factory as well as in a field. In addition, we investigate X-ray irradiation induced discharge of spherical void in epoxy resin. Physical consideration of the effect of X-ray irradiation on void discharges in epoxy resin was also made. Time lag of void discharges in epoxy resin was also made with attenuation of X-ray irradiation dose considered.

Figure 1 shows the relation between phase angle of PD pulse occurrence and apparent charge ($\phi-q$ pattern) for molded electrode sample with various void sizes. Note that all PD pulses appearing in an oscilloscope frame (sampling time: 0.1 s) in twelve times experiments are plotted in each figure. As can be seen, as the size of the void increases, both charge $q$ and the repetition rate increases. It should be noticed that most of PD pulses occur in the vicinity of the phase angle 90 and 270°.

We calculated $t_{inc}$ as well as experimental results as a function of the void diameter $2a$ for different copper plate thickness. It is noticed in the same figure that theoretical and experimental results without X-ray irradiation obtained by L.Niemeyer are also plotted. Symbol and bar of $t_{inc}$ for $d_2=1$ and 2 mm represent the average and maximum and minimum of ten data among twelve experiments excluding the maximum and minimum values. It is found from the figure that the theoretically obtained $t_{inc}$ agrees well with experimental ones. It is also evident that as the diameter of the void increases, the time lag greatly decreases. The results can be interpreted in terms of increase in PD generation probability due to the initial electron supplied from radiation ionization in the void volume caused by X-ray dose.

In this report, we experimentally investigate the effect of X-ray irradiation on fundamental PD behaviors in a spherical void of epoxy resin such as the relation between the void size and apparent charge of PD, and the relation between PD inception voltage and the void size, and the phase resolved characteristics. Time lag of void discharges in epoxy resin was also measured with X-ray irradiation. It was found that a firstly observed PD pulse occur near the positive or negative peak instantaneous voltage and then the next PD pulse occurs at the vicinity of the zero cross phase within one sinusoidal cycle. It was also found that X-ray irradiation to the ER sample with a spherical void allows the discharge time lag to greatly be reduced. Physical consideration of the effect of X-ray irradiation on the characteristics of void discharges in epoxy resin was also made with considering attenuation of X-ray irradiation dose by copper plate inserted between X-ray generation source and the epoxy resin sample.
Calculation of Time-Resolved Energy Distribution of Electrons by PT-FTI Method

Akihide Takeda Member (Shikoku University, takeda@junior.shikoku-u.ac.jp)
Nobuaki Ikuta Member (Tokushima University, nobuaki Ikuta@shirt.ocn.ne.jp)

Keywords: dispersion functions in time and energy domains, successive tracing, constant rate

The Flight Time Integral (FTI) method \(^{(1)}\) utilizes the convergence of the circulation flow rate distribution of electrons through the loop of a flight and a collision to obtain the energy distribution in steady state. A new procedure to obtain the time resolved energy distribution, the Pulsed Townsent-FTI (PT-FTI) method has been developed. In which, electron circulation is traced with iterative operation of loop dispersion functions in time and energy domains \(L(t', \varepsilon_0; t_0, \varepsilon_0)\). Electrons started with the initial rate distribution \(\Psi sn_1(t_0, \varepsilon_0)\) have the \(n\)-th starting rate distribution \(\Psi sn_n(t_0, \varepsilon_0)\) by cascaded \((n-1)\) operations of \(L(t', \varepsilon_0; t_0, \varepsilon_0)\).

\[
\Psi sn_n(t_0, \varepsilon_0) = L(t', \varepsilon_0; t_0, \varepsilon_0)^{n-1} \otimes \Psi sn_1(t_0, \varepsilon_0)
\]

With the increase of operation number \(n\), \(\Psi sn_n(t_0, \varepsilon_0)\) converges in energy but delays in time with dispersion. The \(n\)-th flight behavior is given by an operation of dispersion functions in a flight \(Hf_n(t, \varepsilon; t_0, \varepsilon_0)\) in time and energy domains to \(\Psi sn_n(t_0, \varepsilon_0)\) as

\[
Ff_n(t, \varepsilon, \theta) = \sum_{\ell=0}^{\infty} P_\ell (\cos \theta) Hf_\ell(t, \varepsilon; t_0, \varepsilon_0) \otimes \Psi sn_n(t_0, \varepsilon_0)
\]

\[
Ff_n(t, \varepsilon, \theta) = \sum_{\ell=0}^{\infty} P_\ell (\cos \theta) Ff_\ell(t, \varepsilon) \left[ eV^{-1} \right] \ldots \ldots \ldots \ldots (2)
\]

The sums of \(\Psi sn_n(t_0, \varepsilon_0)\) and \(Ff_n(t, \varepsilon)\) until the \(m\)-th flight give time resolved energy distributions at start \(\Psi sn_{TM}(t_0, \varepsilon_0)\), in flight \(Ff_{TM}(t, \varepsilon, \theta)\) and normalized \(Ff_{TM}(t, \varepsilon, \theta)\), exact before the start of the \(m\)-th flight.

\[
\Psi sn_{TM}(t_0, \varepsilon_0) = \sum_{n=1}^{m} \Psi sn_n(t_0, \varepsilon_0) \left[ s^{-1} eV^{-1} \right] \ldots \ldots \ldots \ldots (3)
\]

\[
Ff_{TM}(t, \varepsilon, \theta) = \sum_{n=1}^{m} Ff_n(t, \varepsilon, \theta) \left[ eV^{-1} \right] \ldots \ldots \ldots \ldots (4)
\]

\[
Ff_{TM}(t, \varepsilon, \theta) = Ff_{TM}(t, \varepsilon, \theta)/Ff_{TM}(t) \left[ eV^{-1} \right] \ldots \ldots \ldots \ldots (5)
\]

\(Ff_{TM}(t, \varepsilon, \theta)\) and \(Ff_{TM}(t, \varepsilon, \theta)\) give the time dependent transport quantities and transport coefficients.

Provisional calculation is performed using simple conditions such that the elastic collision probability in gas of 18.3\(eV^{1/2}\) [cm\(^{-1}\)], the mass ratio \(m/M = 0.01\), the gas density \(N = 1 \times 10^7\) [cm\(^{-3}\)], the reduced electric field of 10[Td], and the initial distribution \(\Psi sn_1(t_0, \varepsilon_0) = \pi^{-1/2} \exp\left[-(\varepsilon_0 - 2)^2\right] \delta(t_0)\). In Fig. 1, the earlier stage of the time resolved energy distribution of electrons in flight \(Ff_{TM}(t, \varepsilon)\) is shown until

\( t = 2 \times 10^{-8} [s]\). Relaxation behavior from higher energy is clearly observed. The energy distribution in the equilibrium region agrees with that obtained by the FTI method. It implies the validity both of FTI and PT-FTI methods. Figure 2 shows the time dependent variation of drift velocity \(\langle v_x \rangle(t)\) and of electron flux \(\Gamma(t)\) through the calculated data \(m = 300\), where the increase of \(\langle v_x \rangle(t)\) is due to the decrease of high energy component and the decrease of \(\Gamma(t)\) is due to the reduction of electron number both after \(m = 300\).

Time resolved energy distribution is obtainable by solving the Boltzmann equation \(^{(2)}\), but PT-FTI method is capable to provide systematic information due the multi-layered composition. It is expected to be helpful to make exact the time resolved transport quantities of electrons changing the number at a constant relative rate.

References


Phenol Decomposition Process by Pulsed-discharge Plasma above a Water Surface in Oxygen and Argon Atmosphere

Haruki Shiota  Student Member  (Muroran Institute of Technology, s1624045@m.mmm.muroran-it.ac.jp)
Hideyuki Itabashi  Member  (Muroran Institute of Technology)
Kohki Satoh  Senior Member  (Muroran Institute of Technology, ksatoh@m.mmm.muroran-it.ac.jp)
Hidenori Itoh  Member  (Muroran Institute of Technology, hitoh@m.mmm.muroran-it.ac.jp)

Keywords: water purification, pulsed discharge, phenol aqueous solution, decomposition process, gas chromatograph mass spectrometry

Recently, water pollution by persistent organic pollutants and volatile chlorinated organic compounds is serious problem, and water treatment techniques using a pulsed discharge have attracted attention. Since the species having high oxidation potential, such as OH, O₃ and H₂O₂, can be produced when pulsed-discharge plasma is generated above or in water, the water treatment can be done effectively using the active species. Hoeben et al.(1) investigated the by-products of phenol decomposed by pulsed discharge plasma generated above a phenol aqueous solution, and reported that OH and O₃ contribute to the decomposition of phenol. They also deduced the decomposition processes of phenol in the aqueous solution, but some of these processes are predicted due to the limited number of measured by-products in the processes. In this work, we minutely investigate the by-products of phenol decomposed by pulsed-discharge plasma generated above a phenol aqueous solution when Ar, O₂ and Ar-O₂ mixture are used as background gases, and we deduce the decomposition processes of phenol from the by-products.

Figure 1 shows the decomposition process of phenol when Ar is used as a background gas. Catechol, hydroquinone and 4-hydroxy-2-cyclohexene-1-on are found to be produced in the phenol aqueous solution sampled after 120 min of plasma exposure, and no O₃ is detected; therefore, active species such as OH, O, HO₂, H₂O₂, which are produced from H₂O in the discharge, can convert phenol into those by-products.

Figure 2 shows the decomposition process of phenol when O₂ is used as a background gas. Formic acid, maleic acid, succinic acid and 4,6-dihydroxy-2,4-hexadienoic acid are found to be produced from phenol in addition to catechol and hydroquinone. O₃ is produced in the discharge plasma, so that the benzene ring of phenol is probably cleaved by 1,3-dipolar addition reaction with O₃, and 4,6-dihydroxy-2,4-hexadienoic acid can be produced. Further, O₃ can cleave a double bond of 4,6-dihydroxy-2,4-hexadienoic acid to produce two fragments, which contain two and four carbon atoms, namely, maleic acid or succinic acid and oxalic acid. Oxalic acid is not detected in this work, but formic acid, which is detected as the by-product of phenol, is produced from oxalic acid as shown in reaction (1)(2). Therefore, oxalic acid can be produced by phenol decomposition.

\[
\text{HOOCCOOH} \rightarrow \text{HCOOH} + \text{CO}_2 \] ............................ (1)

When Ar-O₂ mixture is used as a background gas, formic acid, maleic acid, succinic acid and 4,6-dihydroxy-2,4-hexadienoic acid are detected as by-products, and it is found that the quantity of the by-products are almost proportional to the mixture ratio of O₂ and O₃ concentration.

References


Extended Summary

Improvements on Pulsed Current Sharing in Driving Parallel MOSFETs

Hajime Takagi  Student Member  (Ibaraki University, 10mm618s@hcs.ibaraki.ac.jp)
Masato Orihara  Student Member  (Ibaraki University, 11mm607r@hcs.ibaraki.ac.jp)
Tsutomu Yamada  Student Member  (Ibaraki University, 11mm629h@hcs.ibaraki.ac.jp)
Takeshi Yanagidaira  Member  (Ibaraki University, tyanagi@mx.ibaraki.ac.jp)

Keywords: pulsed power, field effect transistors, parallel connection, transmission line transformer, printed circuit board, wiring inductance

To switch high-voltage and high-current pulses by using MOS (Metal Oxide Semiconductor) transistors, it is necessary to distribute evenly the voltage and current to each elements connected in series and parallel (Fig.1). However, the current flowing in each device is different depending on the series resistance and wiring inductance. In this study we verify improvements on pulsed current sharing among parallel transistors with transmission line transformers being employed.

Figure 2 shows the experimental circuit. It has four transistors (Tr1 ~ Tr4) connected in parallel. Four transistors were arranged in line on a printed circuit board. Gate terminal and, the gate driver, drain terminal and the load are connected by wires (wg1 ~ wg4 and wd1 ~ wd4), respectively. The length of each wire is different. Transmission line transformers are employed at points G (gate) and D (drain).

Figure 3 shows the drain current without transformers. Most of the drain current flows into Tr4, since Tr4 is connected with the shortest wire of the four. Figure 4 shows the result using the transformers. The waveform and amplitude of the currents are the same most of the time.

Temperature of each transistor was measured. When the transformers were not used, dissipation of Tr4 was highest in four transistors. The temperature difference was up to 43 degree Celsius. When the transformers were used at point G or at points G and D, temperature difference was 3 or 4 degree Celsius at the maximum. By using transmission line transformers, dissipation in transistors were equalized.

Rise time of output voltage was improved by using the transmission line transformers; the improvement was 2 nanoseconds. The reason is that the current rises at the same time.

Even if many transistors are arranged in line on a printed circuit board, parallel transistors can be driven simultaneously near the rated current by using the transmission line transformers.
Generation and Diagnostics of N₂/He Atmospheric-pressure Non-equilibrium Plasma by 1 µs Rectangular Pulse Voltage

Hiroyuki Shirai  Student Member  (National Defense Academy)
Toshiki Nakano  Member  (National Defense Academy)
Takeshi Kitajima  Member  (National Defense Academy)

**Keywords**: atmospheric-pressure plasma, non-equilibrium plasma, short-pulse voltage, gas temperature, optical emission spectroscopy, N₂ second positive system bands

1. Introduction

Atmospheric-pressure, non-equilibrium plasmas have been studied extensively because of the high-rate process capability caused by a large amount of the reactants generated at high pressures. The high neutral-electron collision frequency, however, tends to increase the gas temperature of the plasmas. The pulsing of plasma generation is expected to prevent a high-pressure plasma from being heated excessively while the plasma density remains high. Our previous reports have clarified that the gas temperature in a pulsed microhollow cathode discharge plasma remains low in the beginning of a pulsed power application.

In this study, we have measured the temporally resolved optical emission spectra of the N₂ second positive system in the pulsed N₂/He atmospheric-pressure plasma generated by 1 µs rectangular pulse voltage in order to discuss the difference between the plasmas generated by fast-rise, short-pulse voltage and those generated by slow-rise, long-pulse voltage.

2. Experimental Procedure

The atmospheric-pressure plasma is generated through an N₂ (0.5%)/He mixture using a microhollow cathode that has an aperture of 100 µm diameter. The typical flow rate of the N₂/He mixture is 200 sccm. The 1 µs rectangular high-voltage pulses are applied to the 2 mm gap between the anode and the cathode at 50 Hz. The rise time of the pulse voltage is 90 ns. The temporally resolved spectra of the N₂ second-positive-system band emission from the midgap between the electrodes are measured using a 50 cm monochromator and a photon-counting system.

3. Results and Discussion

Figures 1 and 2 represent the temporally resolved spectra of the N₂ second positive system (0,0) band and those of the (0,3) band, respectively. The pulse voltage is 1.85 kV. For both bands, the optical emission intensity goes through a maximum at 0.6 µs after the pulse voltage application. The (0,3) band intensity is lower by a factor of 1/7 than the (0,0) band intensity because of the lower Frank-Condon factor for the (0,3) band. Remarkable difference in the spectrum shape between the (0,0) band and the (0,3) band is wide, rounded-peak profile for the (0,0) band. The nonlinear least square fitting of the computed spectra to the (0,0) band spectra in Fig. 1 by assuming the Boltzmann distribution among the C₃Π_u states revealed that the measured spectra of the (0,0) band are deviated significantly from those computed. In contrast, the measured spectra for the (0,3) band in Fig. 2 are expressed well by the computed spectra. The gas temperature is evaluated to be 350±30 K at 0.6 µs after pulse voltage application.

The peculiar shape of the N₂ second positive system (0,0) band spectra is attributed to the high excitation rate of N₂ to the C³Π_u state which in turn causes the high population of the vibrational ground level in the B³Π_g state. This results in the self-absorption of the (0,0) band emission that distorts the emission spectra. It was confirmed that the distortion of the (0,0) band is reduced in the plasma generated by the lower pulse voltage. This validates the explanation for the appearance of the distorted (0,0) band spectra. The peculiar (0,0) band spectra were not observed for the plasma generated by the slow-rise (about 30 µs), long-pulse (1 ms) voltage, indicating higher electronic excitation rates of N₂ in the plasma generated by the 1 µs pulse voltage.

![Fig. 1. Temporally resolved N₂ emission spectra for (0,0) band](image1)

![Fig. 2. Temporally resolved N₂ emission spectra for (0,3) band](image2)
Mechanical Property and Thermal Endurance of Room Temperature Vulcanizing Silicone Compound with Reduced Environmental Impact

Hiroaki Cho  Member  (Mie University, sn@elec.mie-u.ac.jp)
Yasunori Ashida  Non-member  (Mie University, sn@elec.mie-u.ac.jp)
Shuhei Nakamura  Member  (Mie University, sn@elec.mie-u.ac.jp)
Wataru Shimizu  Non-member  (Shinshu University, yasumura@shinshu-u.ac.jp)
Yasushi Murakami  Non-member  (Shinshu University, yasumura@shinshu-u.ac.jp)

Keywords: silicone composite, organic tin compounds, mechanical properties, thermal endurance, environmental impact

Room temperature vulcanizing (RTV) elastic silicones usually employ organic tin compounds as a hardener. It is well known that they are strong biohazardous. Thus, European Union is going to regulate the use of organic tin compounds and to exclude them from industrial products till 2015. Authors have succeeded in making a substitute of organic tin compounds as a hardener for RTV elastic silicone by using titanium alkoxide and a carboxylate ester as a hardener and a promoter, respectively.

In order to improve the adhesive or mechanical properties, silica particles or coupling agents are generally added to RTV elastic silicones. In this paper, how the RTV silicone composites made with the new hardener are very resistive to high temperature and high humidity environments is presented by comparing with those made with an organic tin compound.

Liquid silanol-terminated poly(dimethylsiloxane) (PDMS) (DMS-S31: Gelest, Inc.) with an average molecular weight (MW) of 30,000 was used as a precursor for the silicones, and methyltrimethoxysilane (MTMS, Shin-Etsu Chemical Co., Ltd.) was used as a crosslinker.

In this paper, a new hardener is made by the combination of titanium alkoxide and a carboxylate ester, in which tetraethylorthotitanate (TTE: Merck & Co., Inc.) and diethyl DL-malate (MA: Tokyo Kasei Kogyo Co., Ltd.) are employed as a new hardener (it is indicated by NHD). In order to compare the effect of the new hardener on mechanical, adhesive and heat endurance properties of RTV silicone to a conventional hardener, dibutyltin dilaurate (it is indicated by SnHD: Tokyo Kasei Kogyo Co., Ltd.) is used. The composition of RTV elastic silicone samples and their notations in figure is shown in Table 1.

A cured film with thickness of about 1.5 mm was obtained for the measurements of mechanical and heat endurance properties. The silane coupling agent (SC) was added to the mixture before cure and then, the mixture was stirred. The samples for the estimation of adhesive strength was prepared onto aluminum plates in the thickness of 200 µm and the area of 20 mm × 20 mm.

Table 1. Composition of RTV elastic silicone samples and their notations in figure

<table>
<thead>
<tr>
<th>Sample</th>
<th>PDMS [g/m²]</th>
<th>MTMS [g/m²]</th>
<th>hardener</th>
<th>silane coupling agent [wt%]</th>
<th>silicone [wt%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHD-R972</td>
<td>100</td>
<td>0.08</td>
<td>0.7</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
</tr>
<tr>
<td>NHD-R972 with SC</td>
<td>100</td>
<td>0.08</td>
<td>0.7</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
</tr>
<tr>
<td>NHD-R972 with SL</td>
<td>100</td>
<td>0.08</td>
<td>0.7</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
</tr>
<tr>
<td>NHD-R972 with SL</td>
<td>100</td>
<td>0.08</td>
<td>0.7</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of silane coupling agent containing glycidoxy group on adhesive strength of silicone composites

Fig. 2. Weight loss of silicone composites made with different hardeners and with or without silane coupling agent after ageing at 120°C in water for 5 days

Figure 1 shows the effect of silane coupling agent containing glycidoxy group on adhesive strength of silicone composites. It can be seen that the adhesive strength is improved by adding SC. On the other hand, the elastic modulus and stress at break are not changed by adding SC. Thus, the SC works at the interface between the surface of the metal substrate and silicone. It was impossible to estimate the adhesive strength of the SnHD-R972 with SC sample because of poor curing.

Another point of interest is the good heat resistive property of the NHD sample. Figure 2 shows the weight loss of silicone composites made with different hardeners and with or without silane coupling agent after ageing at 120°C in water for 5 days. It can be seen that the NHD sample has a better heat resistance than the SnHD sample.

It has been found that the resistance of RTV silicone composites made with the new hardener to high temperature and high humidity environments is better than those made with an organic tin compound hardener. The former composites show better adhesive property than the latter.
Proposal of New Water Electrode Method Used for Short-time Testing Method of Water Treeing and Consideration on Temperature Effects of Water Tree Initiation and Propagation

Hiroaki Uehara  Member  (Kanto Gakuin University, huehara@kanto-gakuin.ac.jp)
Katsutoshi Kudo  Member  (Meiji University, katsuto@isc.meiji.ac.jp)
Yoshihiro Ishikawa  Member  (Toshiba Mitsubishi-Electric Industrial Systems Corporation)
Teruo Kanekawa  Member  (Toshiba Mitsubishi-Electric Industrial Systems Corporation)
Yuichi Tsuboi  Member  (Toshiba Mitsubishi-Electric Industrial Systems Corporation)
Kodai Ushiwata  Member  (Toshiba Mitsubishi-Electric Industrial Systems Corporation)
Tetsuo Yoshimitsu  Member  (Toshiba Mitsubishi-Electric Industrial Systems Corporation)

Keywords : water tree, initiation, propagation, temperature, waveform

Research on water treeing has mostly been performed under the application of a high-frequency ac voltage. However, in recent years, the use of rotating electrical machines with an inverter has become widespread owing to their contribution to the prevention of global warming, high effectiveness and the reduced maintenance required. In an underwater motor driven by the voltage of an inverter, it is necessary to consider the water treeing of the motor insulation and the cable insulation connected to the drive board. Up to now, we have performed accelerated deterioration tests. However, in the case of inverter waveform, an accelerated deterioration test cannot be performed because the inverter waveform becomes markedly different from that of an actual machine when the basic frequency is increased. Therefore, there is a possibility of committing a mistake in real-machine reliability evaluation because the initiation and propagation mechanisms are different from those in the case of a real-machine even if we can reproduce water treeing by increasing the basic frequency. In this paper, we investigated the new water electrode method and the temperature effects on water tree initiation and propagation.

The water tree at high temperature does not propagate easily when a voltage is applied in the normal water electrode, as shown in Fig. 1. On the other hand, the water tree at high temperature propagates considerably when a voltage is applied in the new water electrode, as shown in Fig. 2.

Furthermore, we compared the test results obtained at 500Hz and 50Hz at different temperature, as shown in Figs. 2 and 3. These phenomena can be understood by the water diffusion model, as shown in Fig. 4.

Fig. 1. Water tree patterns (normal water electrode, 3kVrms, 500Hz)
Fig. 2. Water tree patterns (new water electrode, 2kVrms, 500Hz)
Fig. 3. Water tree patterns (new water electrode, 2kVrms, 50Hz)
Fig. 4. Water diffusion model