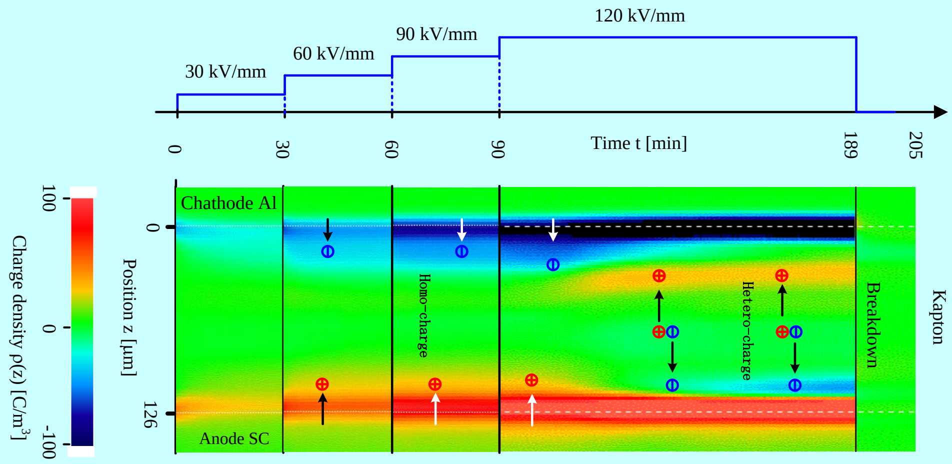
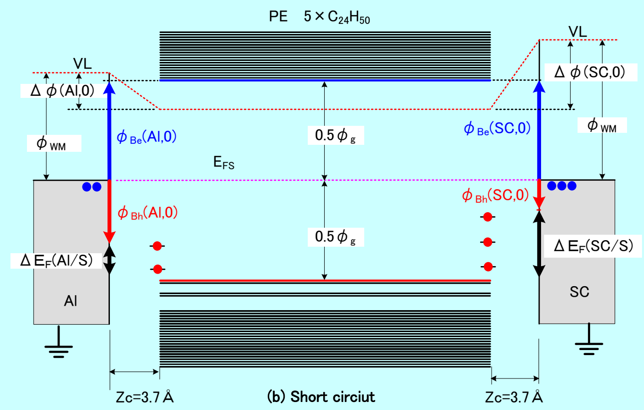
Measurement of Space Charge Accumulation in Dielectric Materials and Analysis using Quantum Chemical Calculation

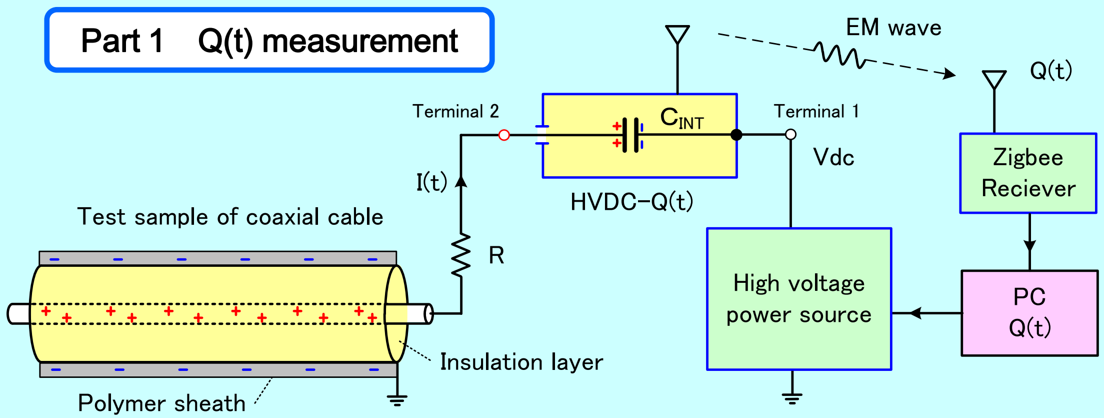


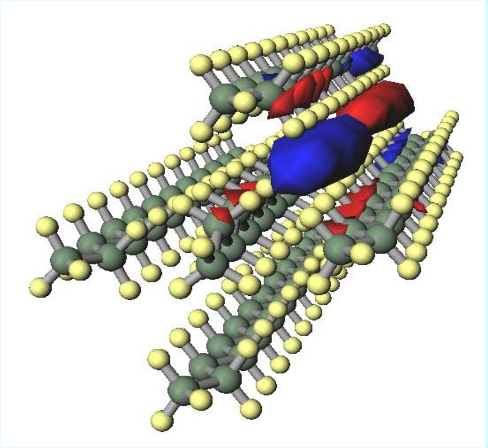
Part 2 PEA measurement



Part 3 Analysis by Quantum Chemical Calculation

Part 1 Q(t) measurement

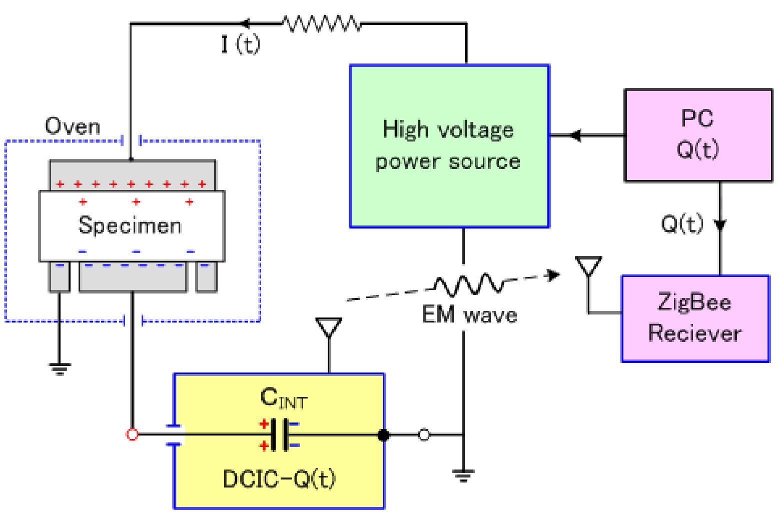




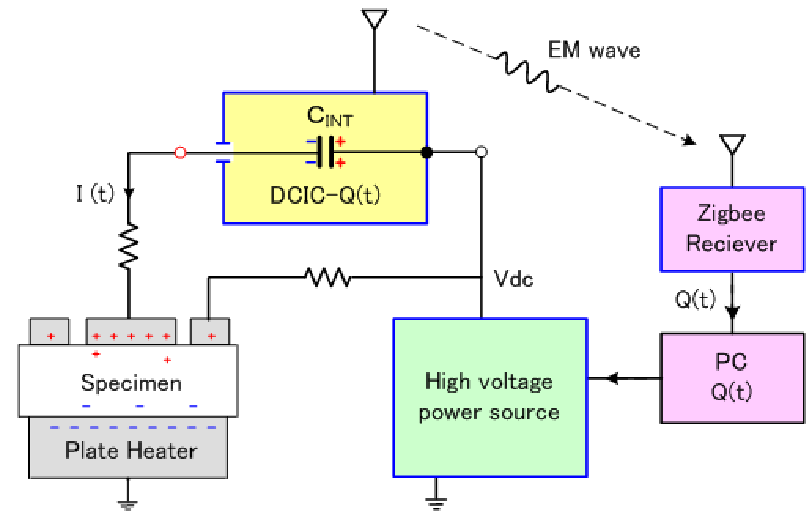
Tatsuo TAKADA takada@a03.itscom.net , Emeritus Professor Tokyo City University / IEEE Fellow

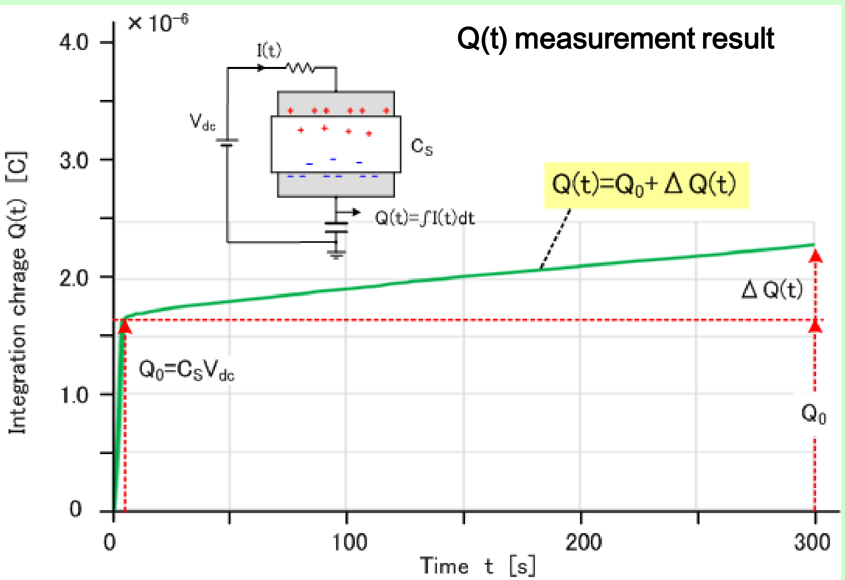
Part 1 Q(t) measurement

< Q(t)Measurement Protocol /Low voltage side >

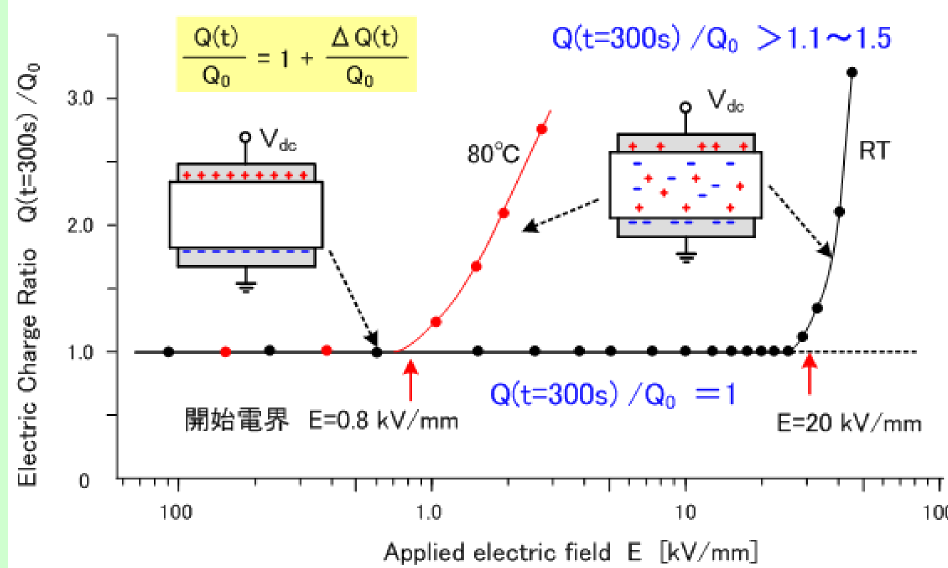


< Q(t)Measurement Protocol /High voltage side >

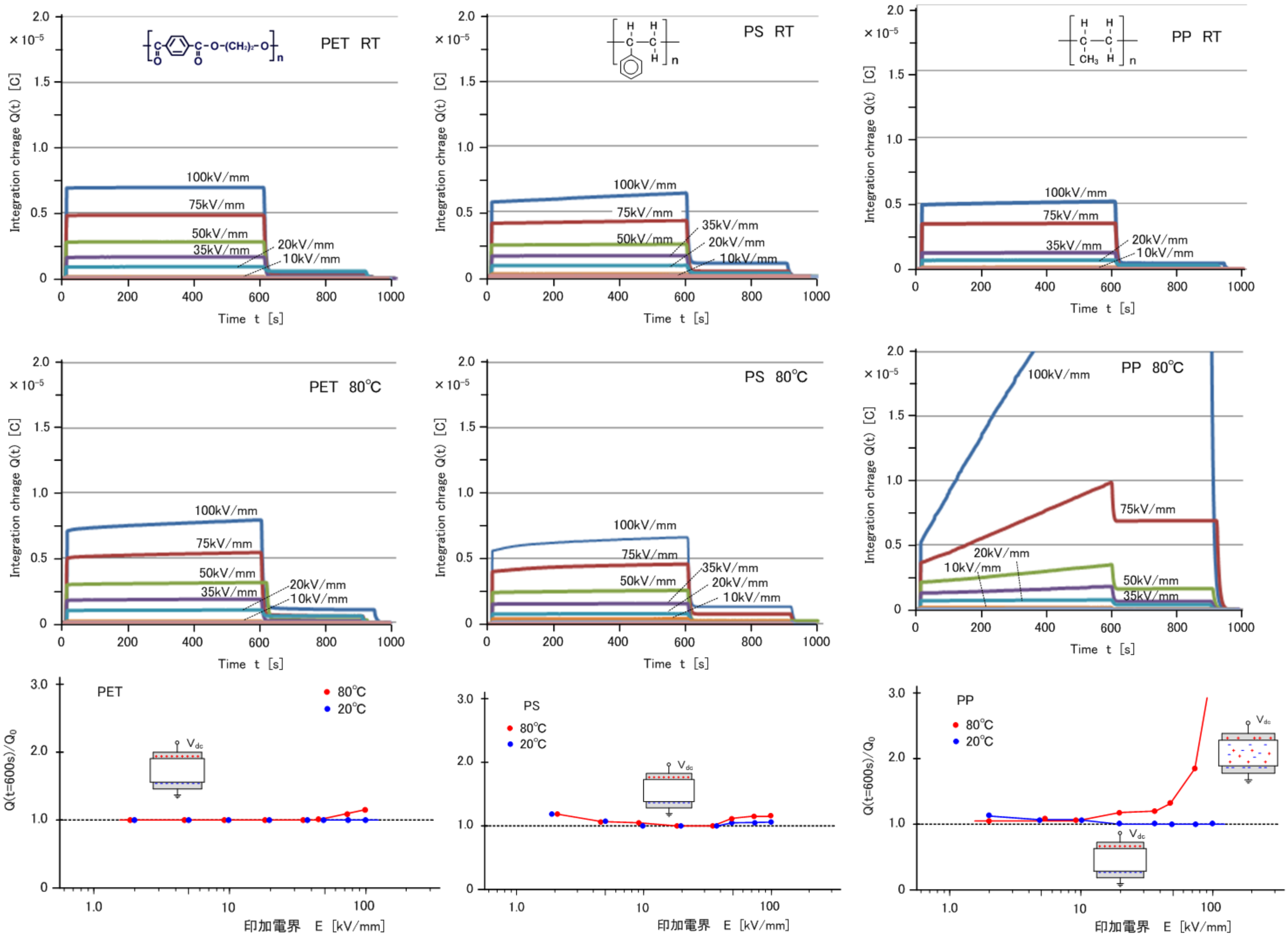




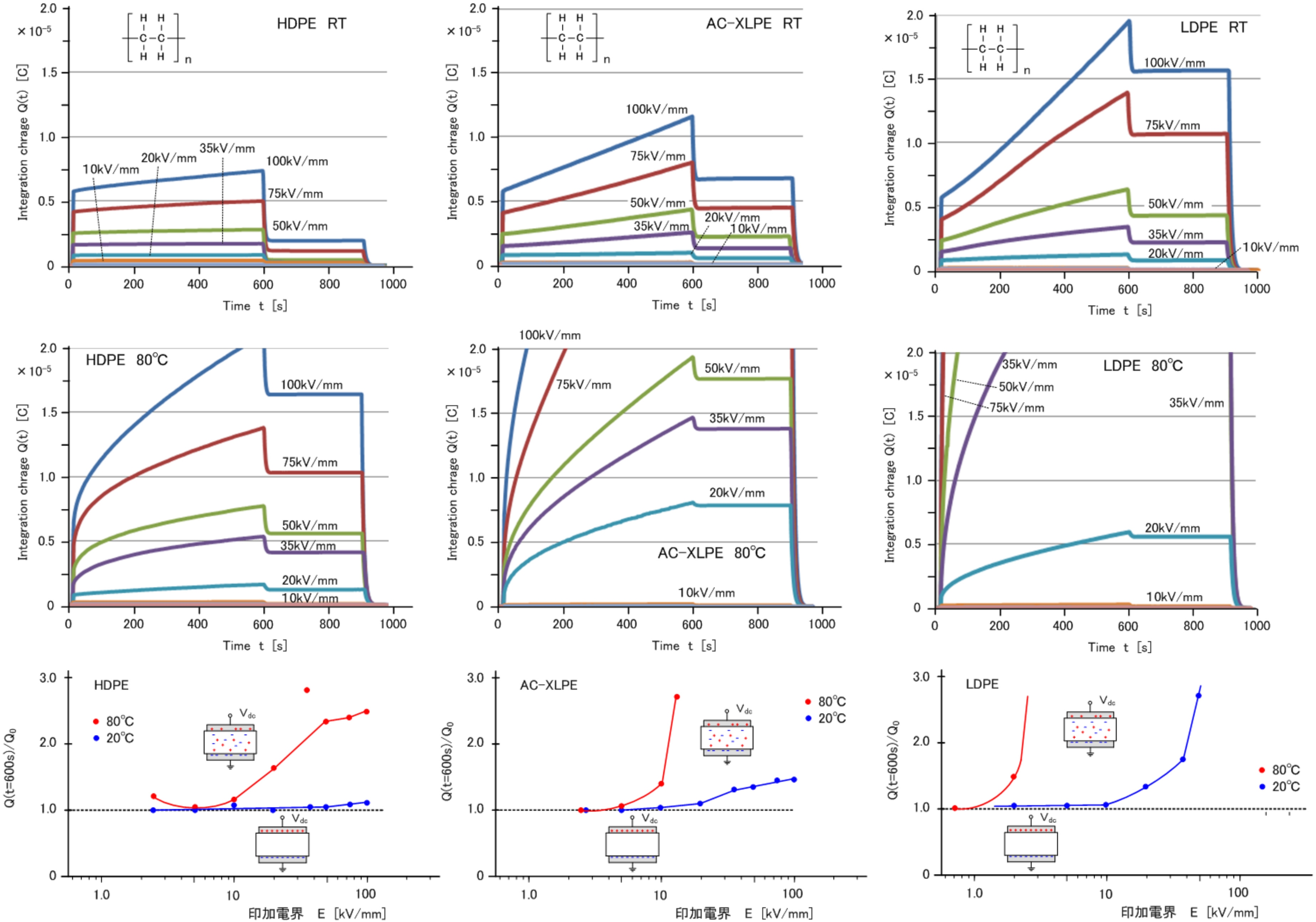
Electric field threshold of charge accumulation



Q(t) measurement results (Difficult for charge accumulation in aromatic polymer)

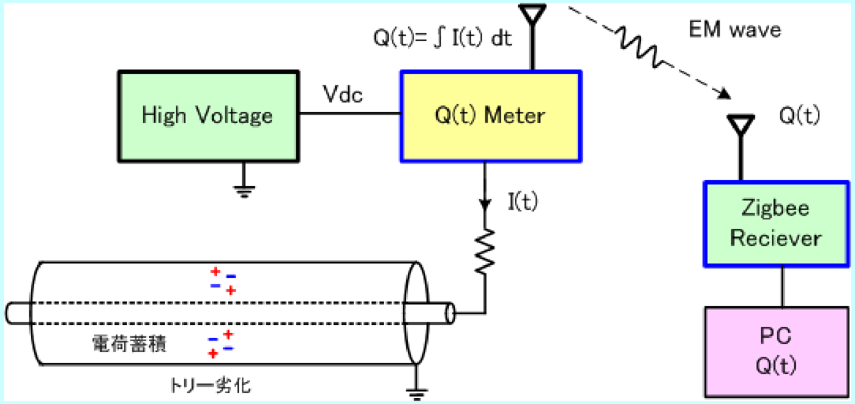


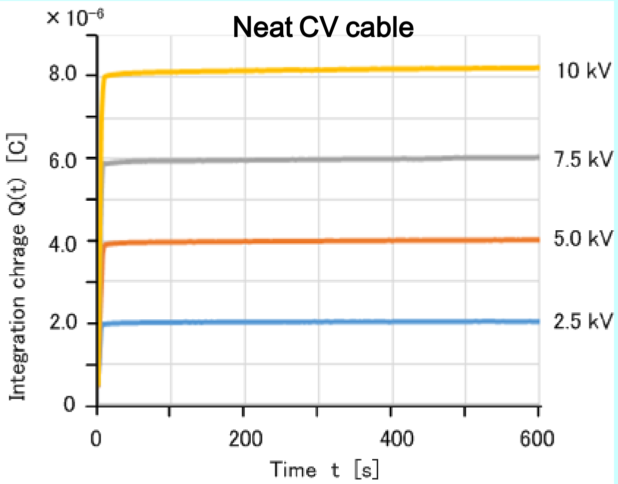
Q(t) measurement results (Easy for charge accumulation in olefin polymer)



Q(t) Measurement: Water-tree Deteriorated CV Cable

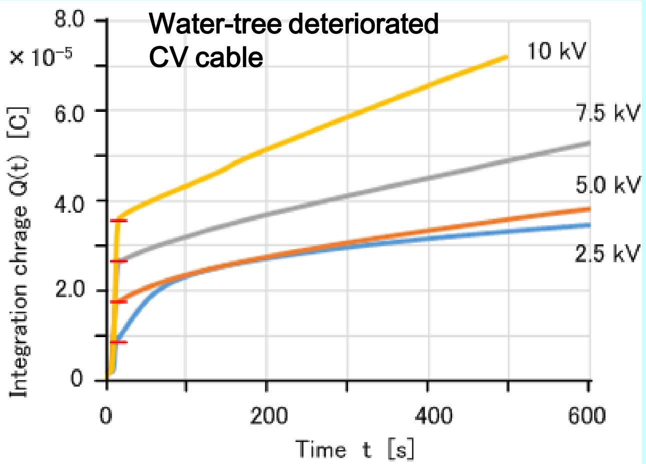
Q(t) device is set on high voltage side

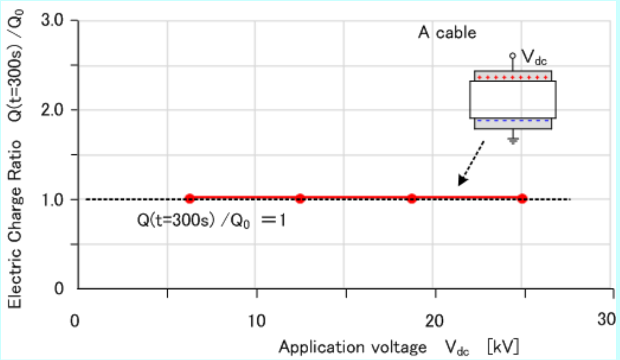




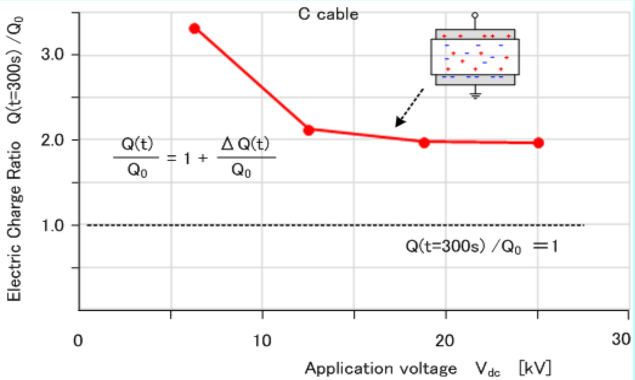
Evaluation on electric charge accumulation

No charge accumulation
→ No deterioration

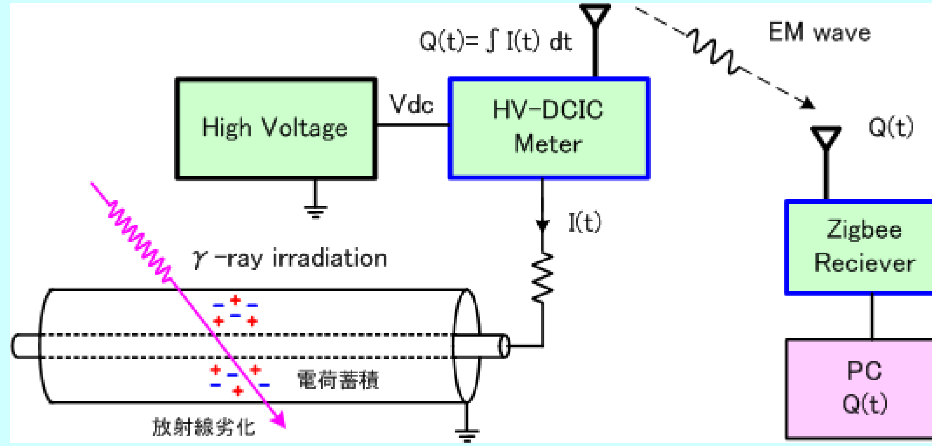


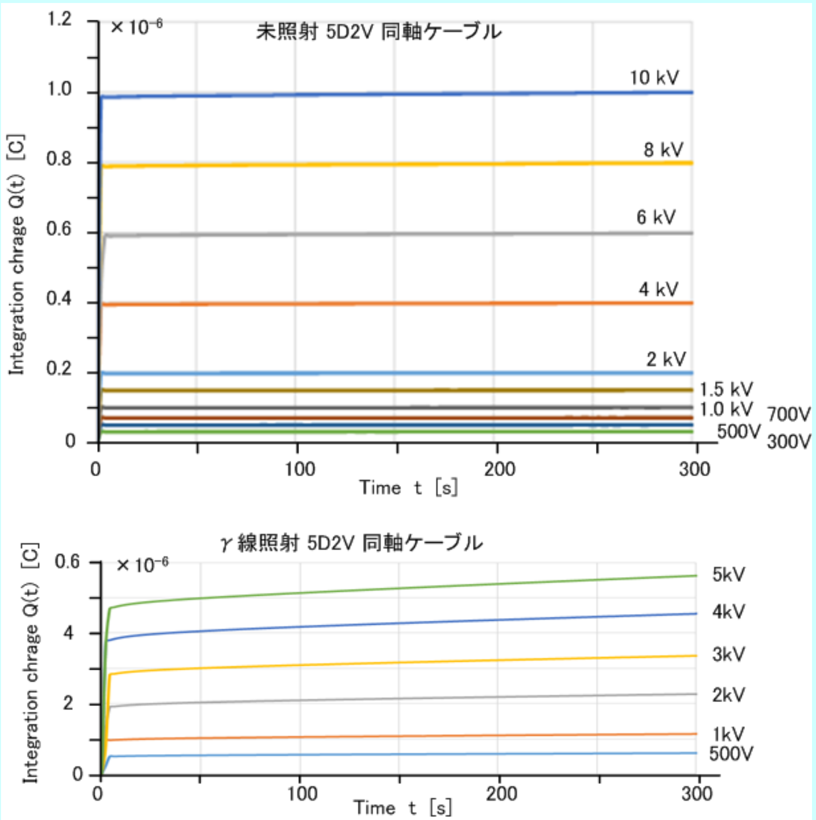


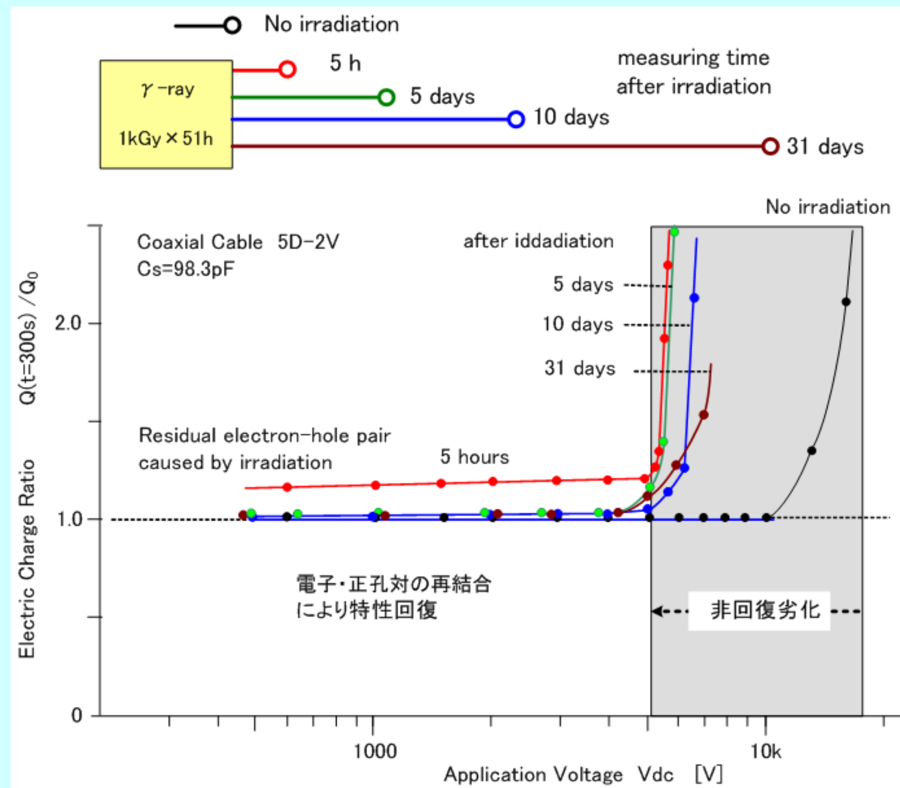
Some charge accumulation
→ deterioration



Q(t) Measurement: Gamma-ray irradiated cable







Generation of electron/hole pair by gamma-ray irradiation in cable
→ the electron/hole pair are recombined by the thermal energy and an applied electric field.

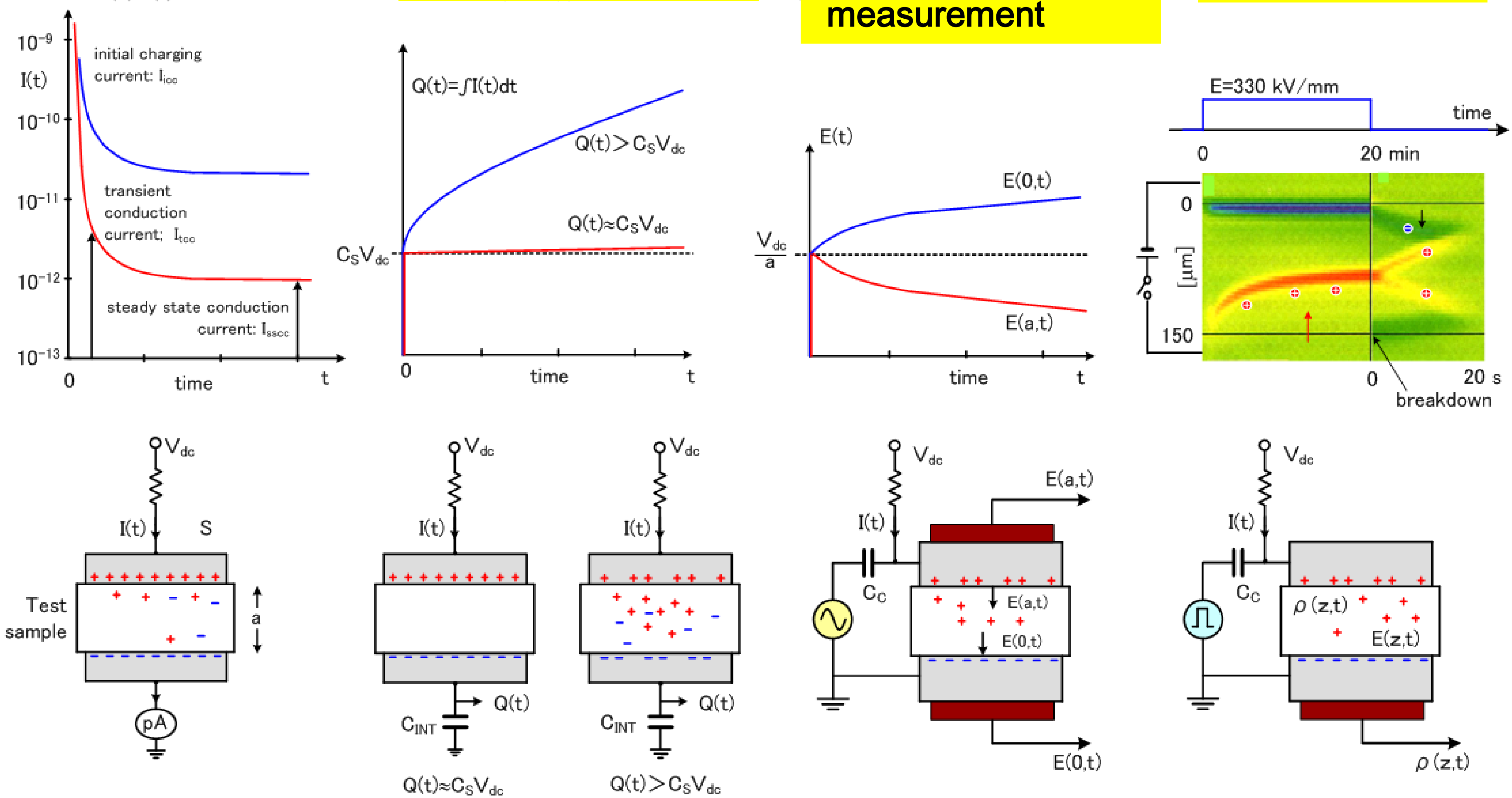
Charge Measurement Methods of DC insulating materials

I(t) measurement

Q(t) measurement

E(0,t) and E(a,t) measurement

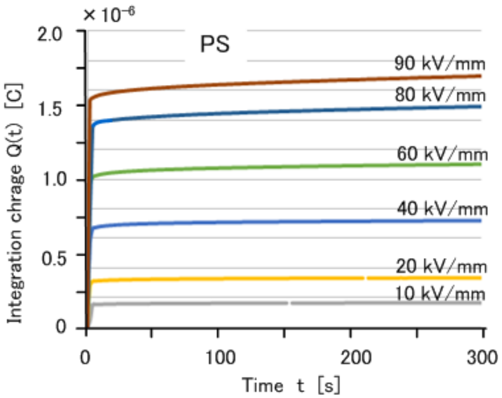
PEA method

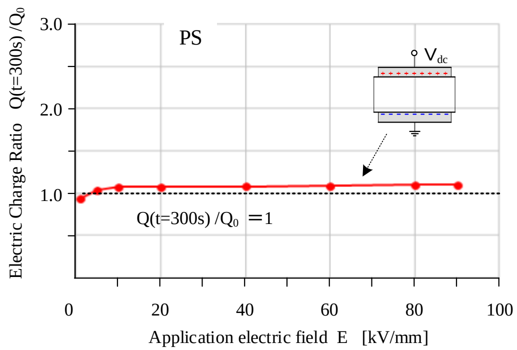


< Q(t) Measurement >

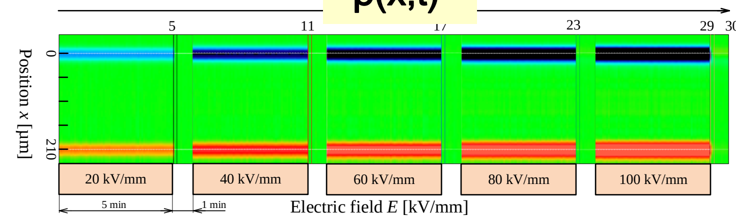
< PEA Method >

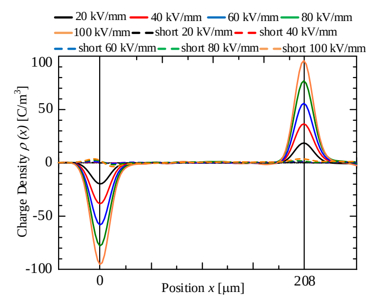
Q(t) and PEA give same properties results

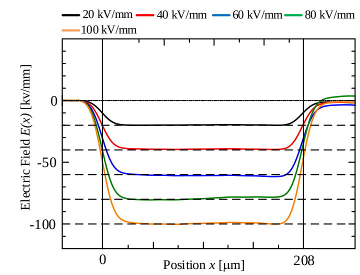




ρ(x,t)





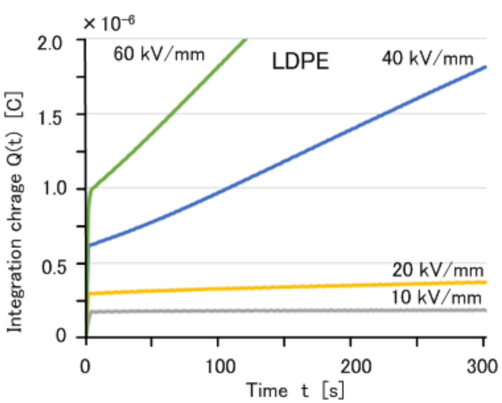


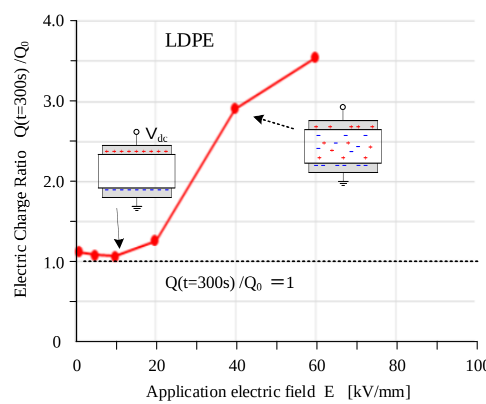
PS (polyethylene) : little charge accumulation.

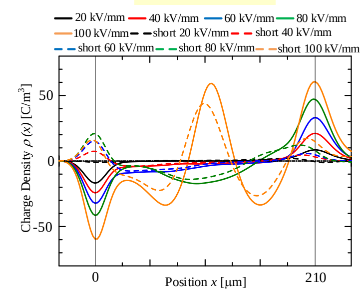
ρ(x,t)

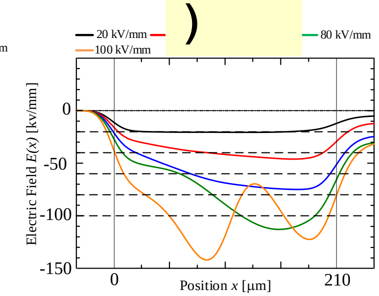
E(x,t
)

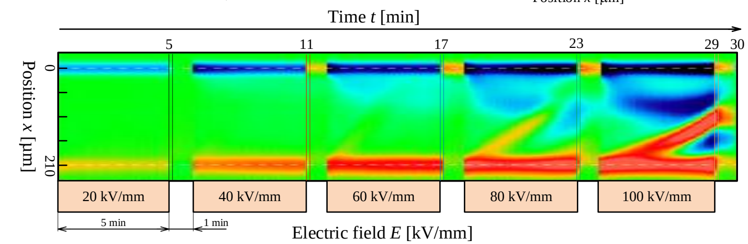
LDPE (low density polyethylene): large amounts of charge accumulation.





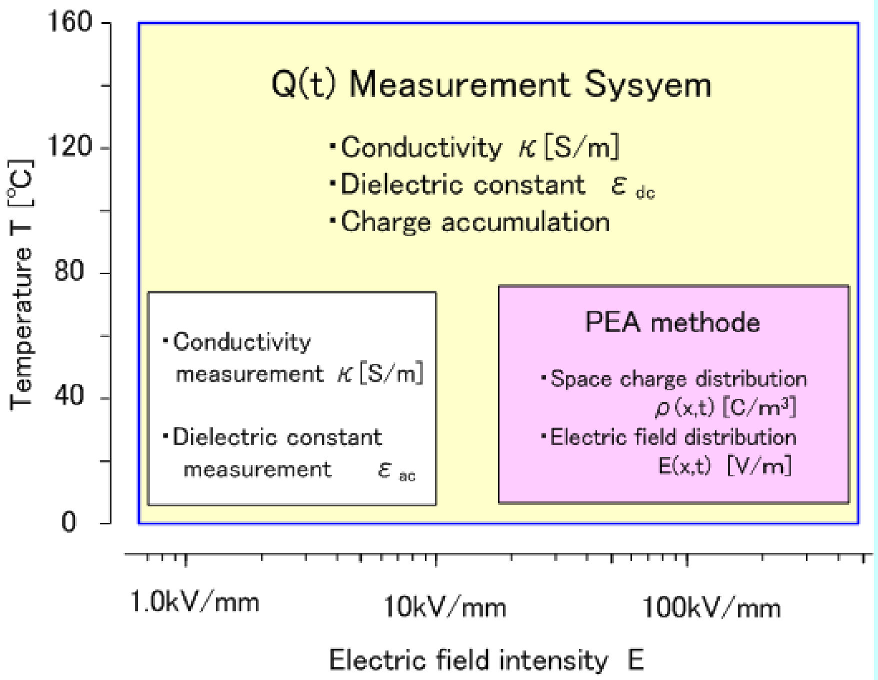






ρ(x,t)

Comparison among various methods of DC insulating material properties



Q(t) method:
wide range of tested temperature and electric stress

Q(t) method

Table Comparison between measurements for electric charge properties

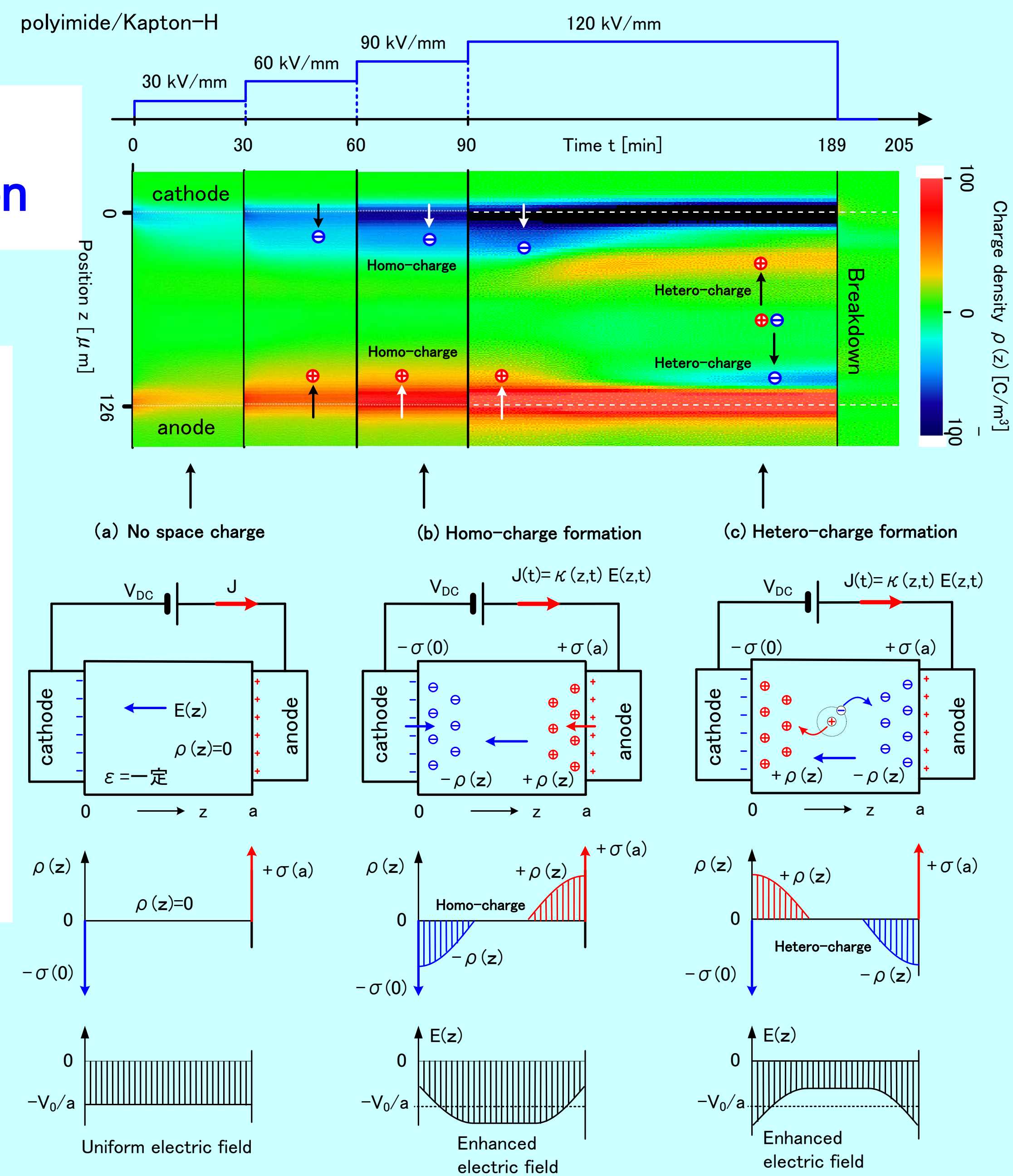
	I(t) measurement	Q(t) method	PEA method
Measurement Principle	Pico-ammeter	Current integration	Electro-acoustic transducer
Space charge distribution	×	×	◎
Evaluation of charge accumulation	×	◎	○
Conductivity κ [S/m]	◎	◎	×
Dielectric constant ε_r	×	◎	×

Part 2 **PEA measurement**

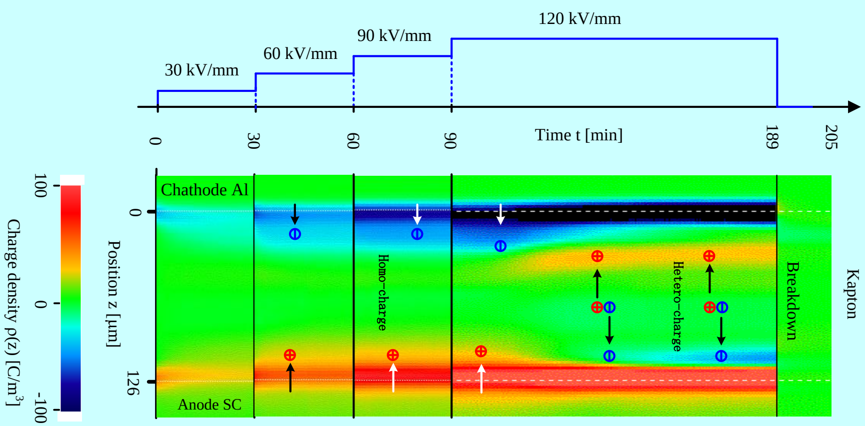
A ：Research Subjects on HVDC Electrical Insulation

・ Internal electric field distortion caused by charge accumulation leads to an electrical breakdown of insulating materials

・ Electric charge accumulation is one of significant factor for studying the properties of insulating materials

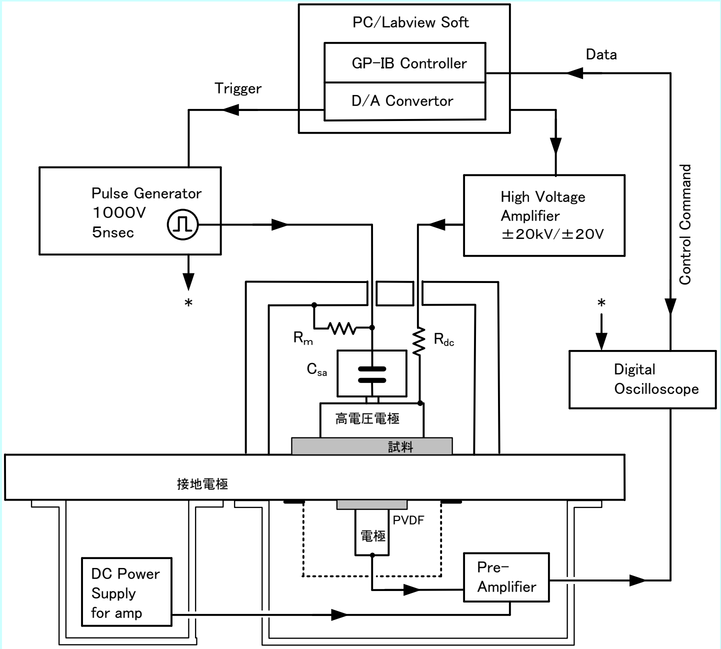


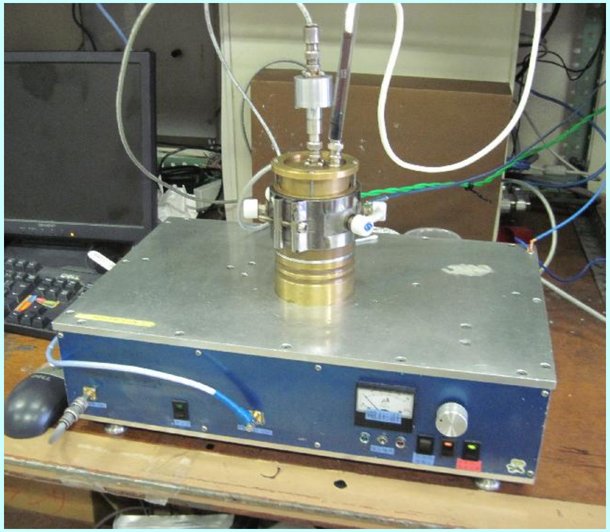
B ：Measurements of Space Charge Accumulation / PEA & PWP



B-1 PEA space charge distribution measurement for sheet sample

PEA measurement result of space charge accumulation in Kapton film under a different electric filed and an elevated temperature.



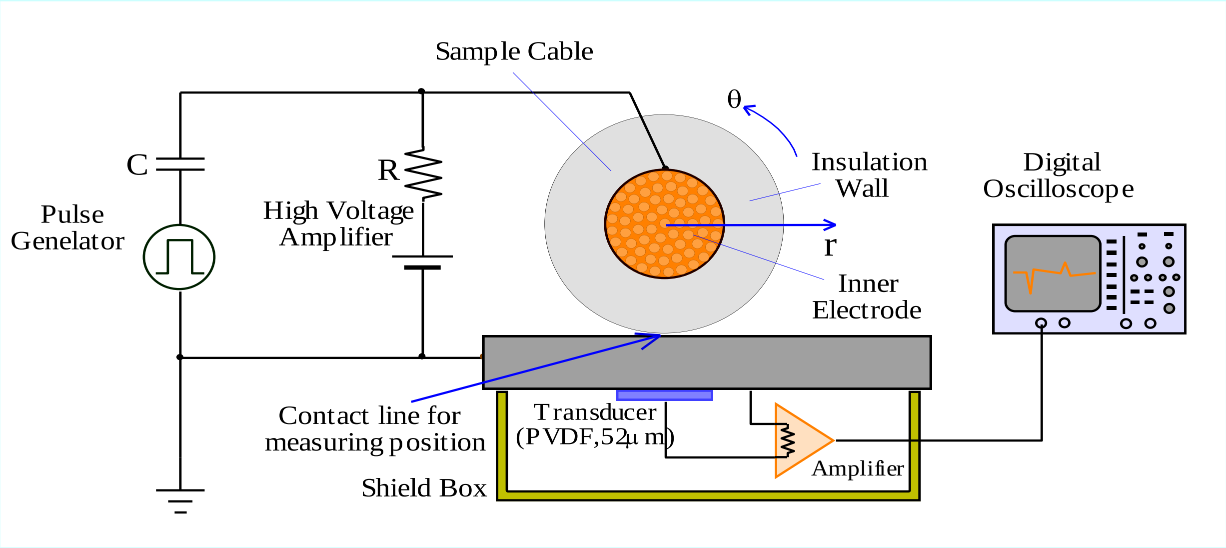


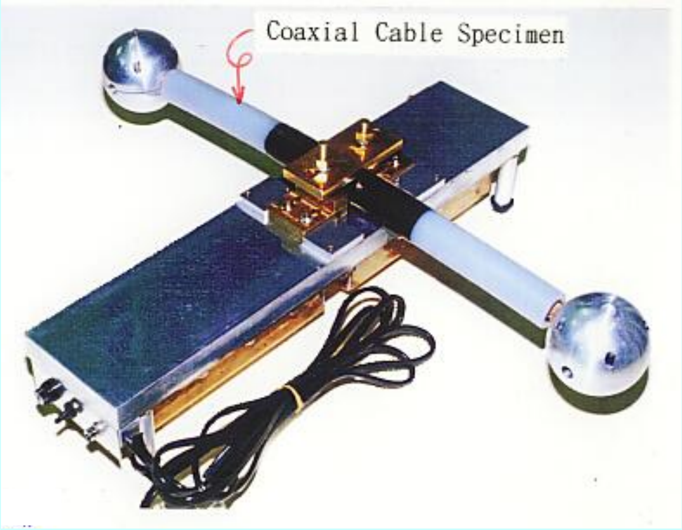
High temperature ＰＥＡ system

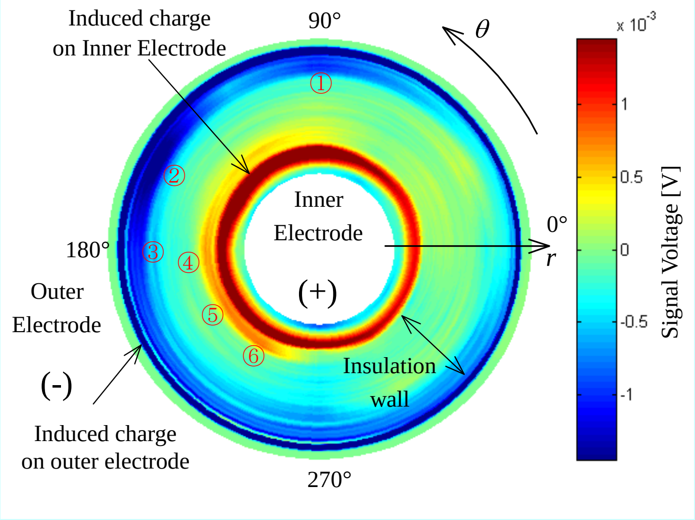
ＰＥＡ:　Pulsed Electro-Acoustic method
PWP: Pressure Wave Propagation method

Ying Li and T. takada, “Progress in Space Charge Measurement of Solid Insulating Materials in Japan, ”IEEE Electrical Insulating Magazine, Vol.10, No.6, pp.16-28, September/October (1994)

B-2 PEA measurement for Observing Charge Accumulation in Cross Section (r, θ) in Cable Geometry

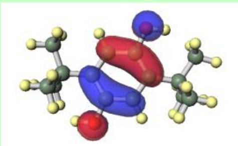


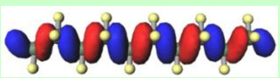




Measurement result of accumulated charge

Part 3 Analysis by Quantum Chemical Calculation





＜Q(t)　Measurement＞

Measurement of basic electric properties

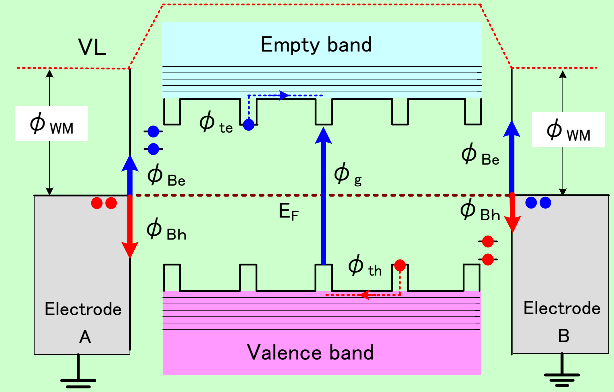
- Charge accumulation　$\Delta Q(t)/Q_0$
- Conductivity　κ [S/m]
- Dielectric constant　ε_r

$Q(t)=Q_0+\Delta Q(t)$ measurement and Evaluation of $\Delta Q(t)/Q_0$

- Electric field dependence
- Temperature
- Time dependence

＜High temperature・ space charge measurements＞

- PEA measurement technology
- Charge density distribution measurement $\rho(x,t,T)$ [C/m^3]



＜Quantum Chemical Calculation＞

Calculation of fundamental function for dielectric materials

- Energy gap　ϕ_g
- Electrode charge injection barrier ϕ_B
- Charge trap depth　ϕ_t

＜Mechanism of charge accumulation in dielectric materials＞

- Dominant：electrode charge injection
- Dominant：electrode charge transfer
- Dominant：electrode charge generation

＜Mechanism of insulation deterioration＞

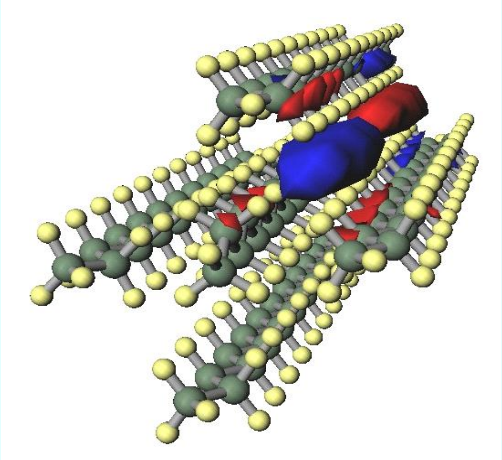
- Observation of energy level variation caused by charge accumulation
- Breaking the molecular chain by the accelerated electron under high electric field

Consultant Contents

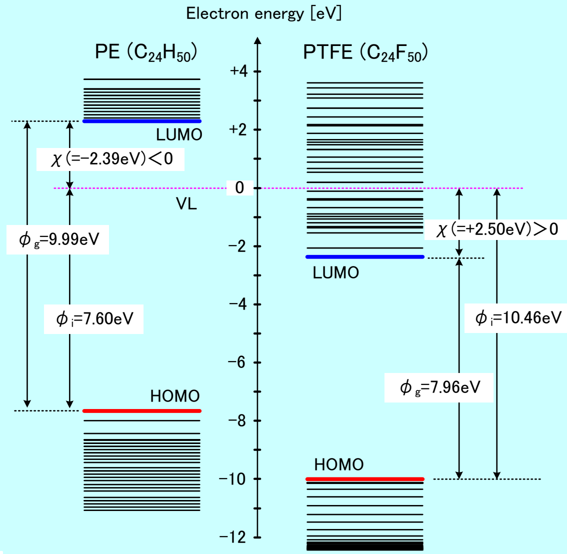
- **Measurement technology of space charge accumulation in dielectric materials**
- **Evaluation and analysis of HVDC insulating materials in new energy power system.**
- **Evaluation and its analysis for high field DC insulating materials in a power electronic device.**

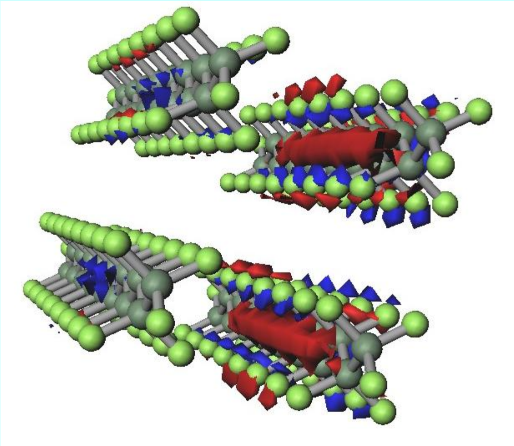
C: Fundamental Electronic Parameters of Insulating Materials by using Quantum Chemical Calculation

Energy level distribution and related parameters

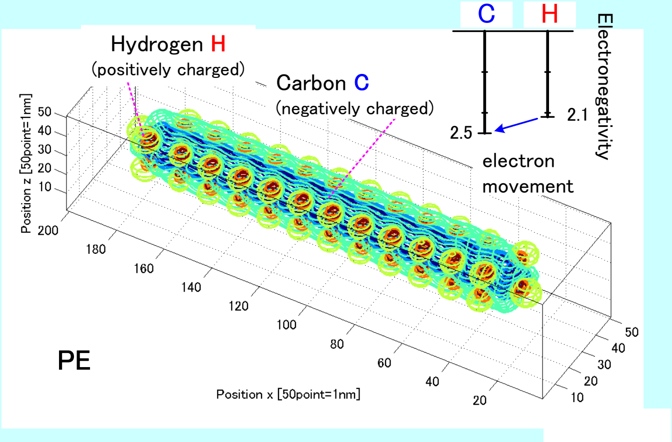


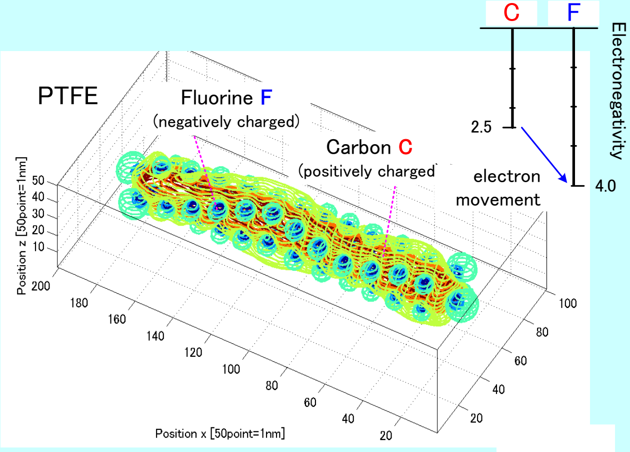
Molecular orbital of PE





Molecular orbital of PTFE





3-demensional electro-static potential distribution

D: Analysis of Electric Charge Accumulation in Dielectrics

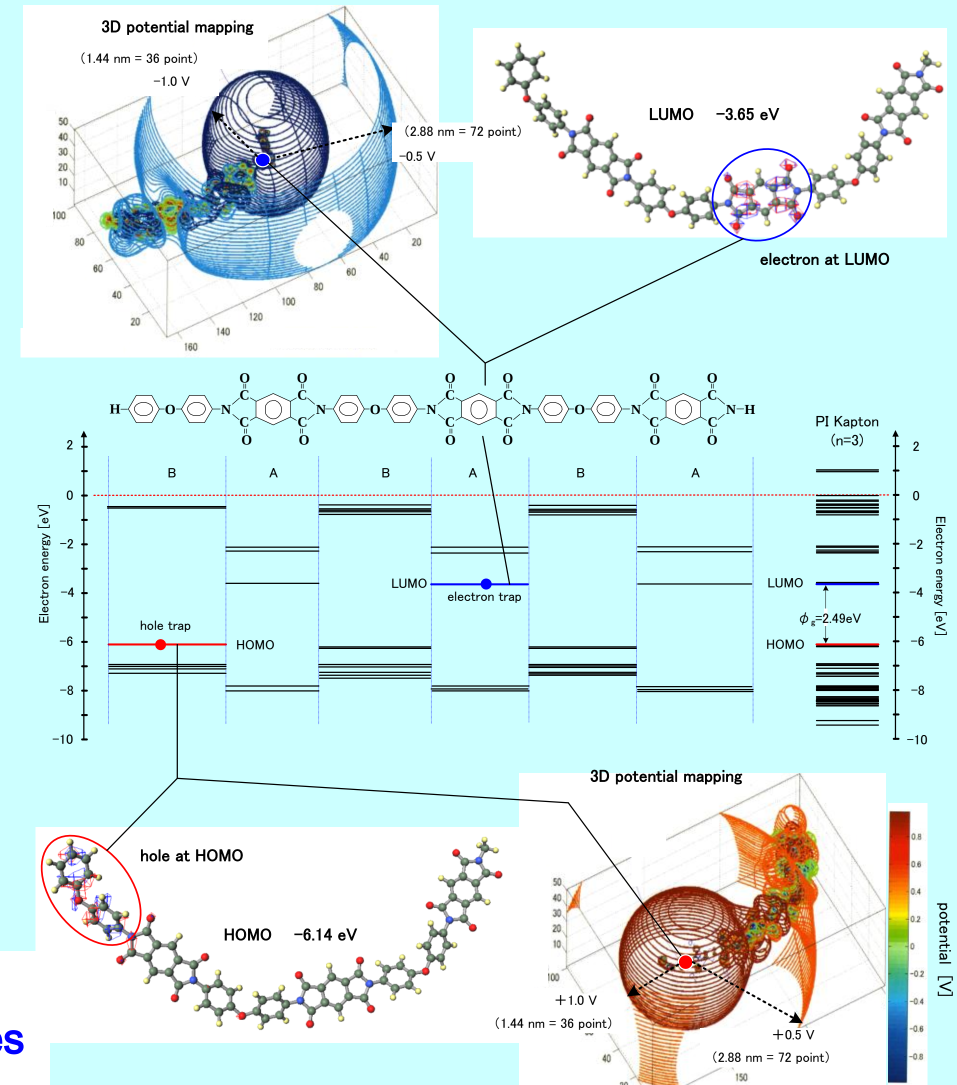
・ Electron energy level distribution is calculated by Quantum Chemical Calculation. →

・ Electron and hole trapping sites are introduced on the main chain which are determined by chemical molecular structure. →

・ 3-dimensional electro-static potential distribution for positively and negatively charged chains was calculated by Quantum Chemical Calculation. →

・ It is clearly found that the potential distortion is located at the estimated trapping sites on the chemical molecular structure.

3D electro-static potential distribution for negatively charged PI/Kapton



3D electro-static potential distribution for positively charged PI/Kapton

Quantum Chemical Calculation is very useful to analyze the charge accumulation properties of insulating materials.

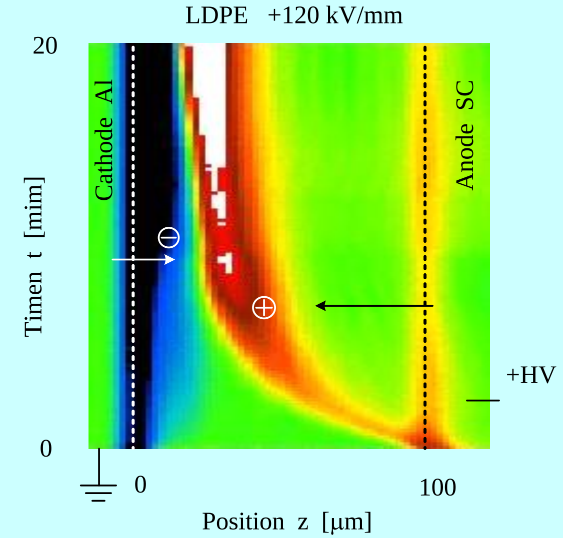
D: Analysis of Electric Charge Accumulation in Dielectrics

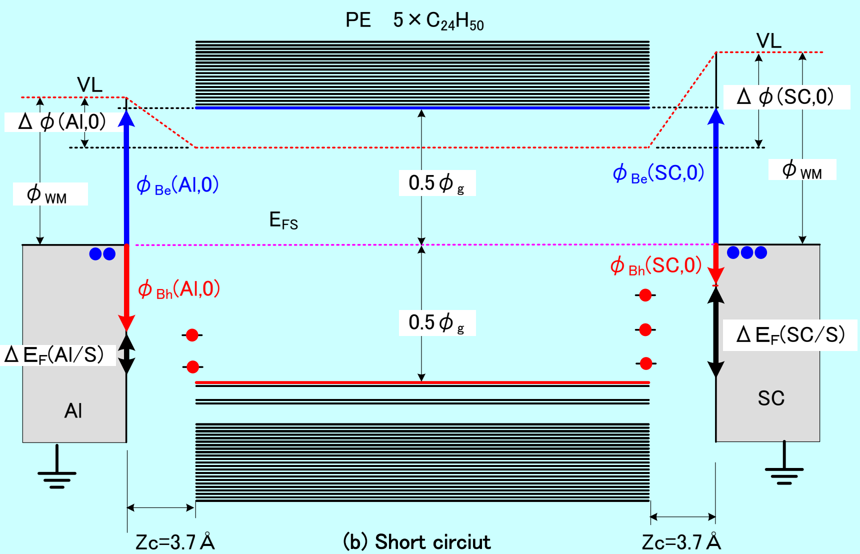
・ Positive charge injection from anode into polyethylene under high electric filed stress is observed by PEA method. →

・ Why does the positive charge inject significantly in PE? →

・ The barrier high (ϕ_B) of hole carrier is evaluated by using Quantum Chemical Calculation. →

・ It is found that the hole carrier injection barrier from semi-conducting electrode is low, leading to the positive charge accumulation.



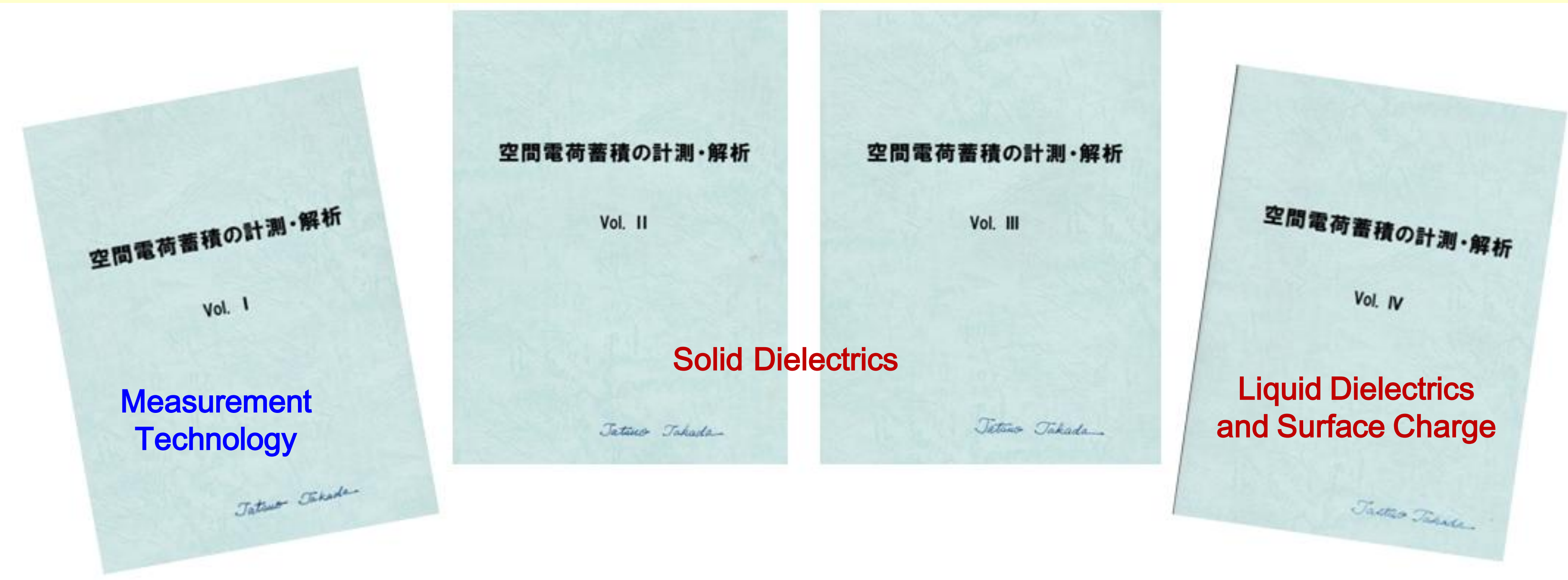


Key subjects:

□ PEA measurement

□ Quantum Chemical Calculation

Series of "Space Charge Accumulation in Dielectrics and Quantum Chemical Calculation Analysis"



Key issues for dielectrics investigation:

(1) Classical theory of electro-magnetic and dielectric physics

(2) Measurement technology and signal processing

(3) Quantum chemical calculation.