RF Dielectric Properties of SiC Ceramic Absorbers for the ARES Cavity

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Notation

- Permittivity

$$\varepsilon = \varepsilon' - j\,\varepsilon''$$

$$\varepsilon_r = \varepsilon/\varepsilon_0 = \varepsilon_r' - j\,\varepsilon_r''$$

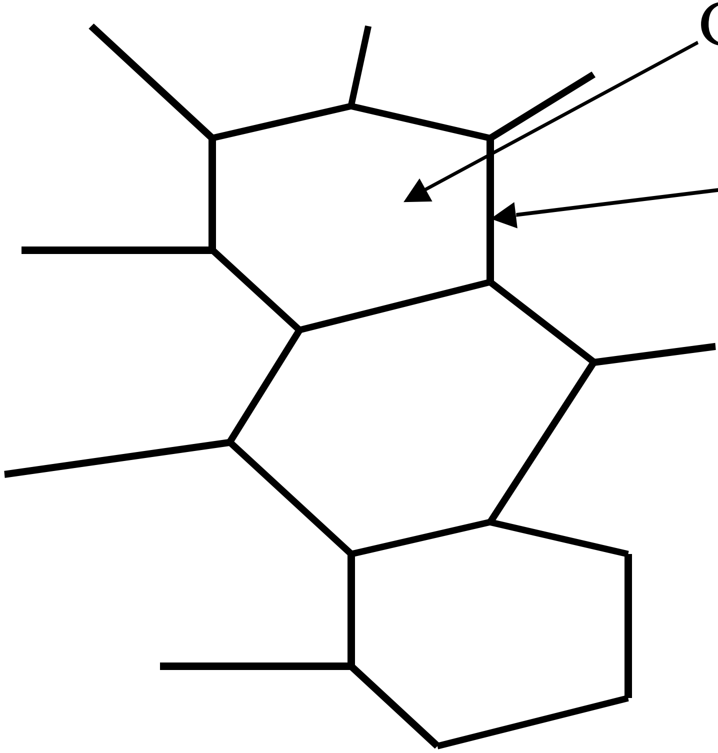
?

- Single crystal of SiC ⇒ Semiconductor.
- SiC ceramics (polycrystal structure) have larger dielectric constant and loss tangent than the single crystal SiC.

- **Where do these different dielectric properties come from?**

!

Dielectric properties are explained by the structure of the grain and grain boundary.

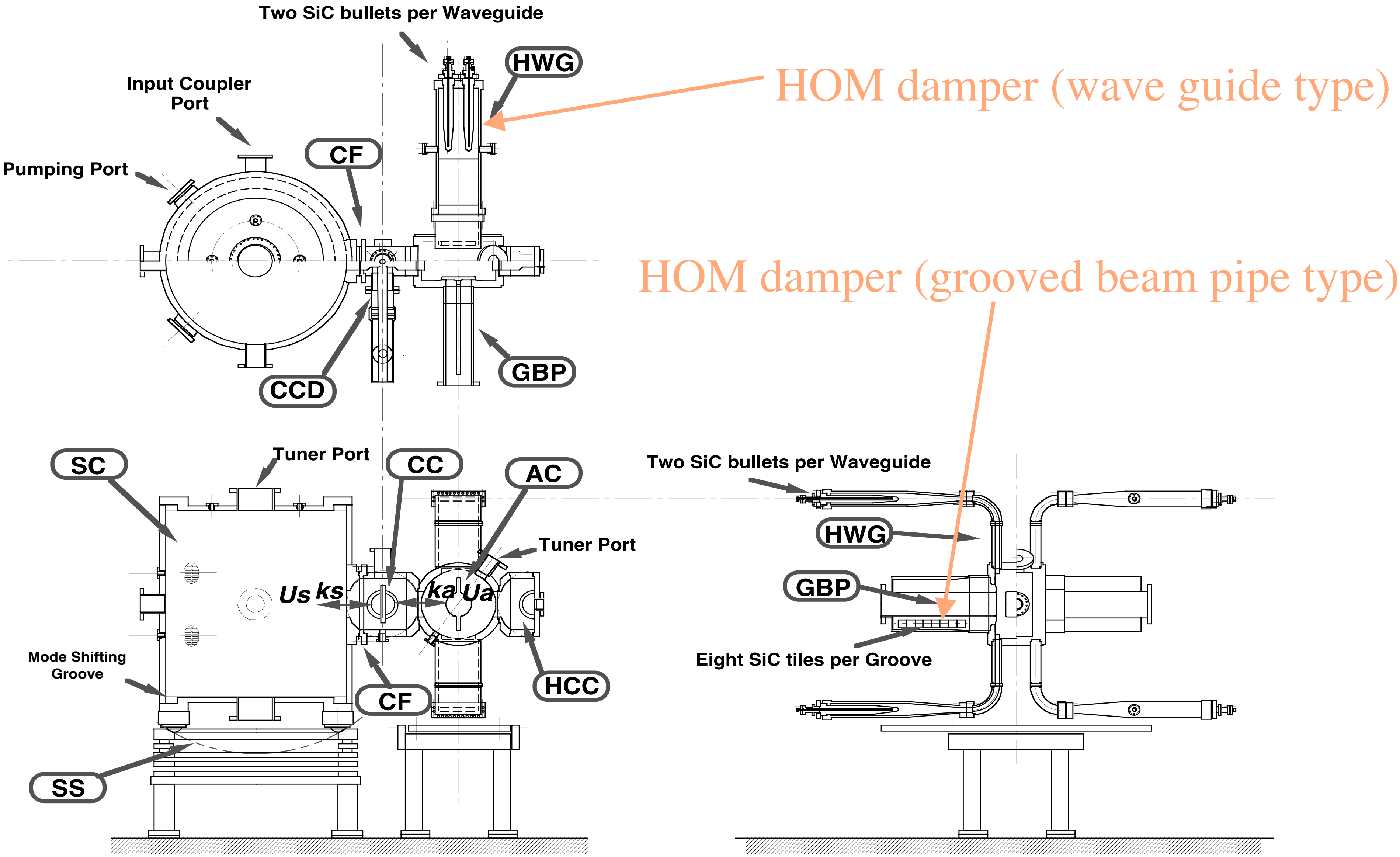


Grain : low resistivity, p-type semiconductor

Depletion layer near grain boundary : high resistivity

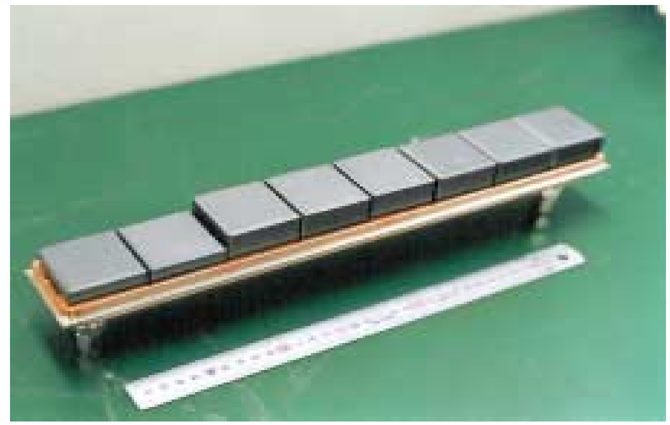
* These dielectric properties of SiC ceramics were predicted by Dr. Maeda et al. (Hitachi co.) in 1985 .

ARES Cavity



Two SiC bullets per Waveguide
HWG
HOM damper (wave guide type)
Input Coupler Port
CF
Pumping Port
HOM damper (grooved beam pipe type)
CCD
GBP
SC
Tuner Port
CC
AC
Two SiC bullets per Waveguide
HWG
Tuner Port
GBP
Us
ks
ka
Ua
Eight SiC tiles per Groove
Mode Shifting Groove
CF
HCC
SS

Two types of SiC ceramics



SiC-A

Bullet shape SiC ceramics
(wave guide type HOM damper)

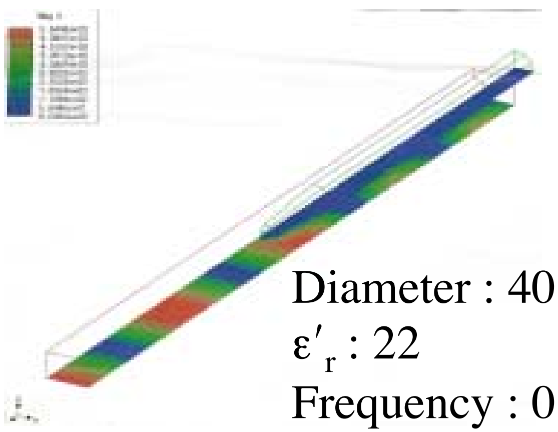
SiC-B

SiC tile
(grooved beam pipe type
HOM damper)

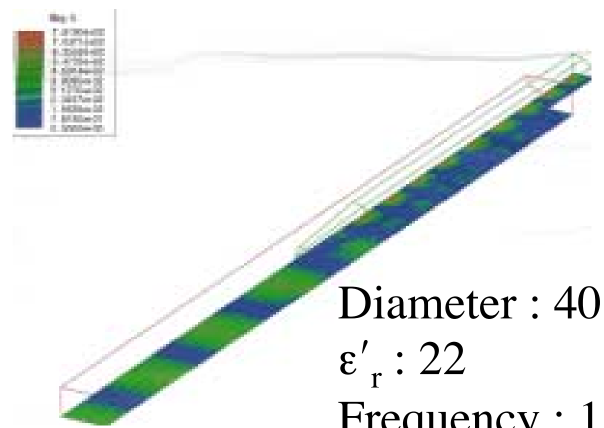
Both SiC ceramics are α-type and sintered at normal pressure.

Boron is used as an additive on densification.

ε' is important parameter as well as ε''



Diameter : 40 mm
ε'_r : 22
Frequency : 0.7 GHz
f_c : ~0.9 GHz



Diameter : 40 mm
ε'_r : 22
Frequency : 1.5 GHz
f_c : ~0.9 GHz

Dielectric rod in a parallel plate line.
Frequency < f_c : HE_{11} mode propagates outside the rod mainly.
Frequency > f_c : HE_{11} mode is propagates inside the rod.
Critical frequency (= f_c) is a function of ε' and diameter of the rod.

*Y.Takeuchi et al. "The SiC Absorber for the KEKB ARES Cavity", EPAC 96.

Measurement of permittivity

- ε', ε''
- Measured with

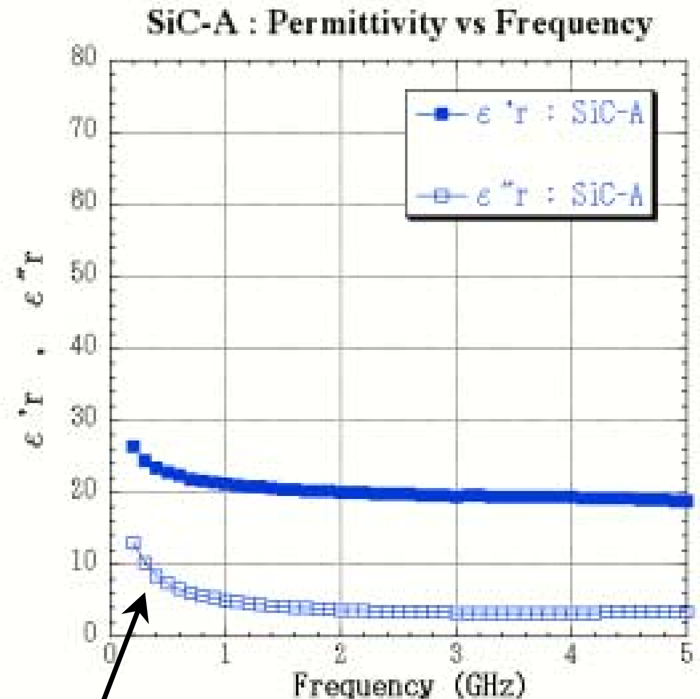
  HP85070B Dielectric Probe Kit+HP8510C Network Analyzer
- Frequency range

  0.2~10 GHz. 0.1GHz step.
- Samples

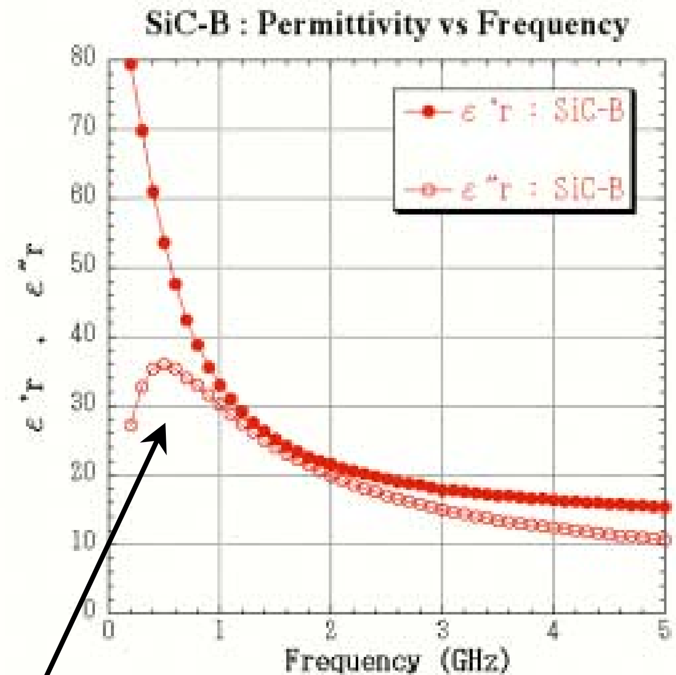
  All sintered lots.

Typical Permittivities of the SiC Ceramics

SiC-A



SiC-B



Dielectric relaxation ?

Dielectric relaxation.
This curve behavior is like a Debye-type relaxation.

Debye Model

Input : Step function

Output : $P_0(t)=P_0(1-e^{-t/\tau})$

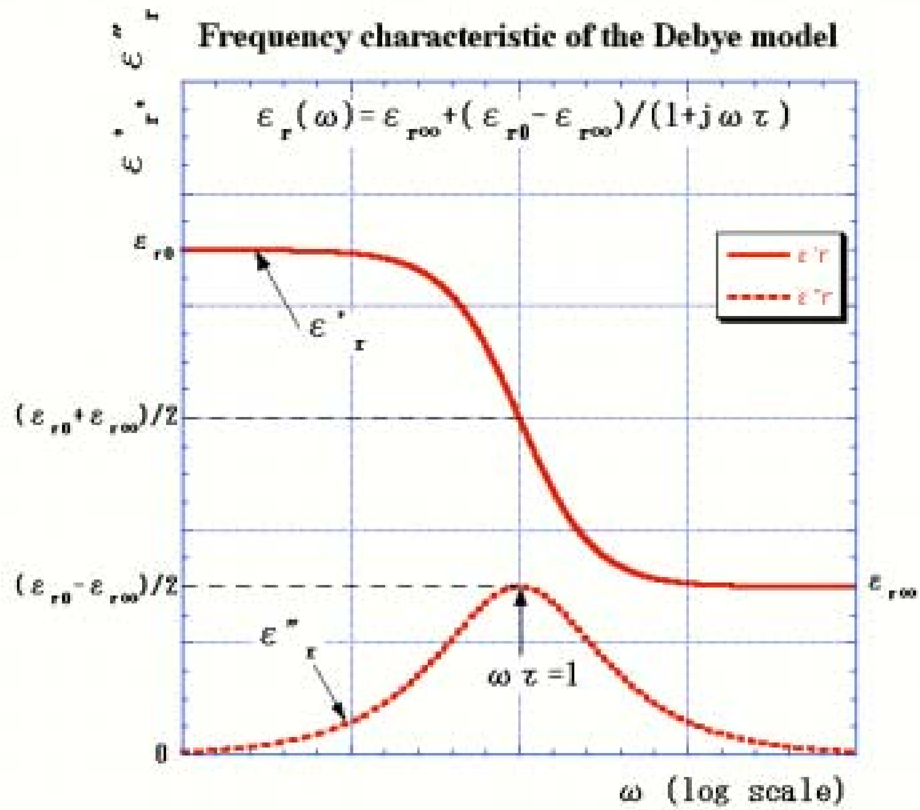
Debye equation

$$\varepsilon_r(\omega) = \varepsilon_{r\infty} + \frac{\varepsilon_{r0} - \varepsilon_{r\infty}}{1 + j\omega\tau} \qquad (1)$$

where $\varepsilon_{r0}=\varepsilon_r'(\omega=0)$, $\varepsilon_{r\infty}=\varepsilon_r'(\omega=\infty)$

τ : relaxation time.

Debye model is characterized by the three parameters, $\varepsilon_{r0,}$ $\varepsilon_{r\infty}$ and τ.

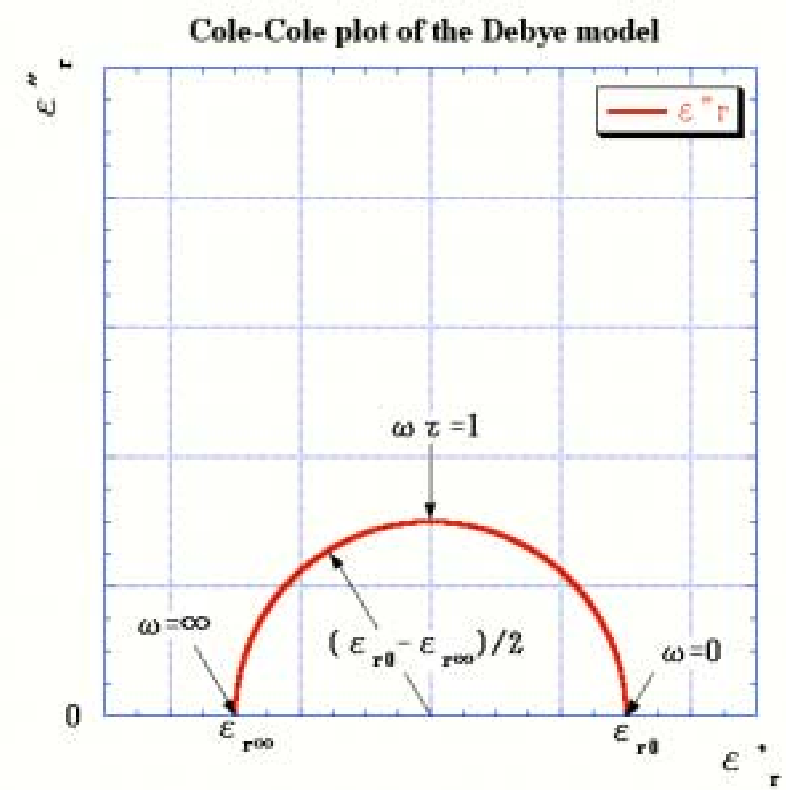


Cole-Cole Diagram

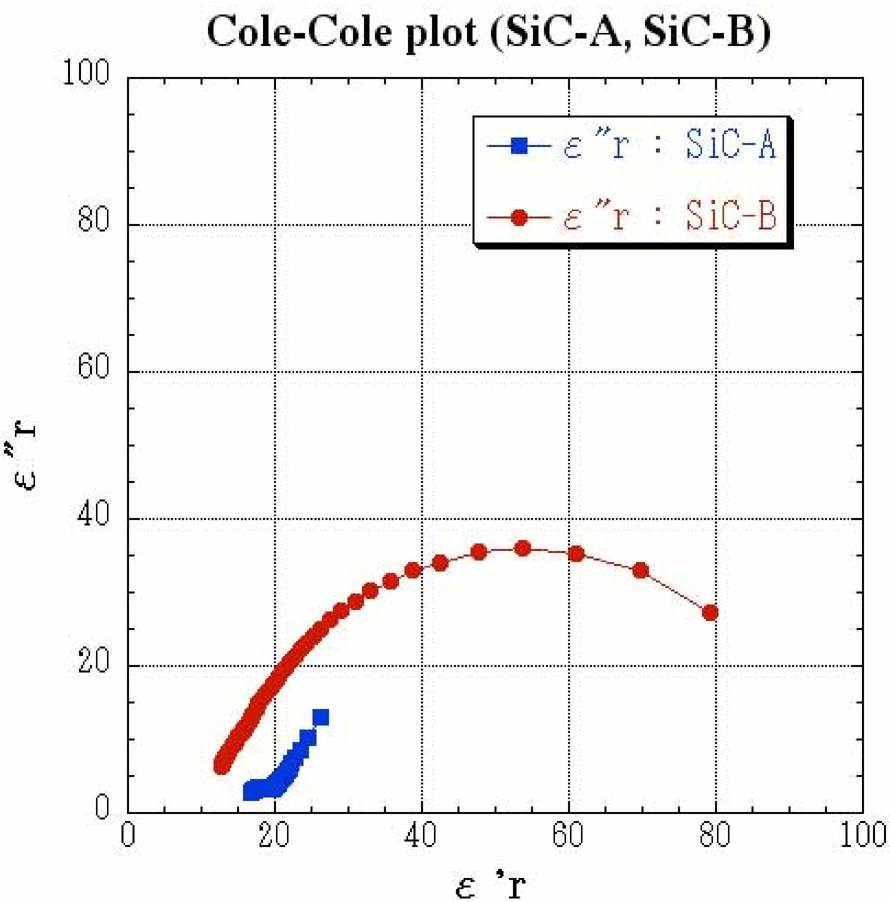
- Horizontal axis : ε_r'
- Vertical axis : ε_r''

Locus (Debye model)

$\Rightarrow$ half circle



Cole-Cole Diagram of SiC-A and SiC-B



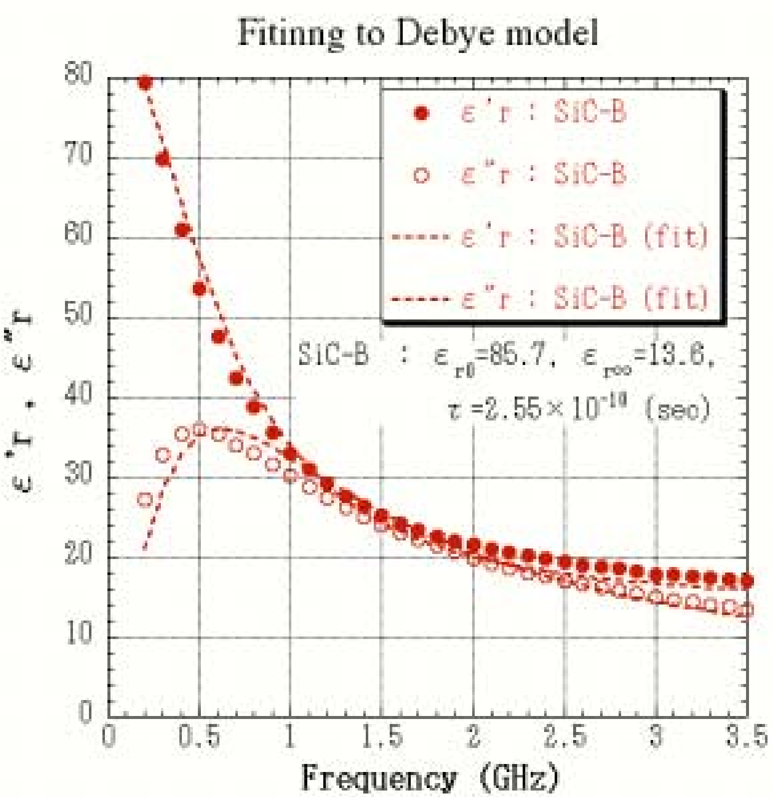
SiC-B

⇒ Debye type

Dielectric

Relaxation

Three Parameters of Debye Model (SiC-B)

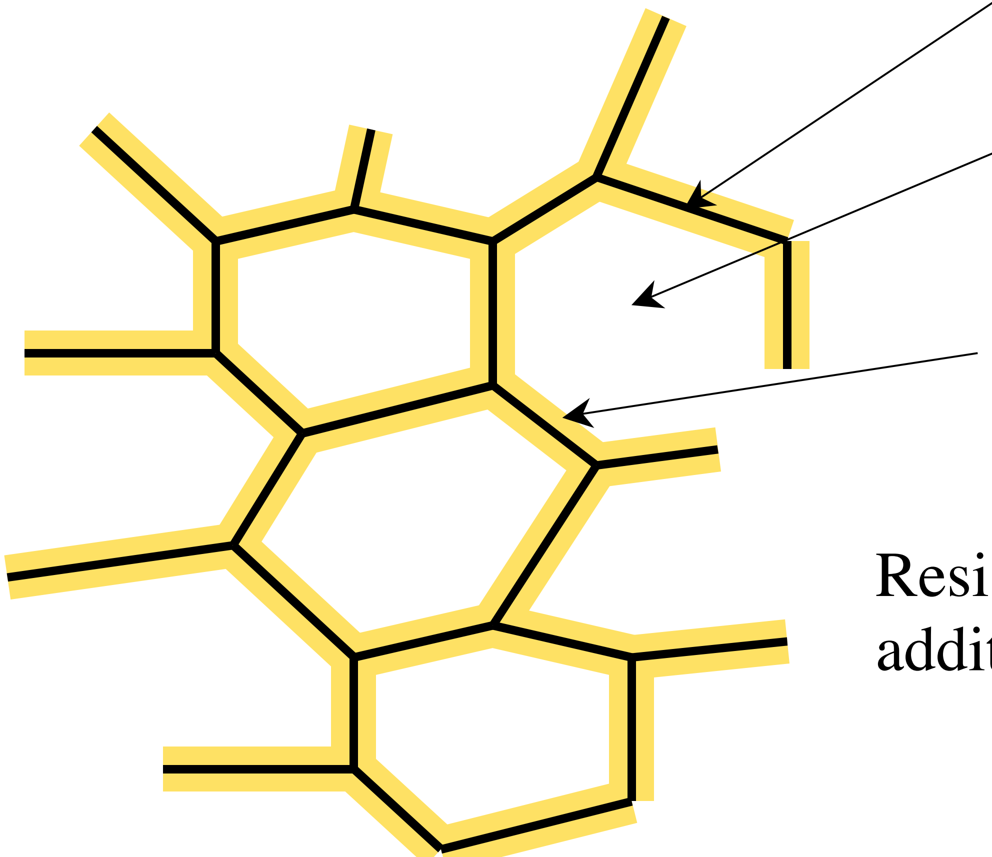


$\varepsilon_{r0} = 85.7$

$\varepsilon_{r\infty} = 13.6$

$\tau = 2.55 \times 10^{-10}$ (sec)

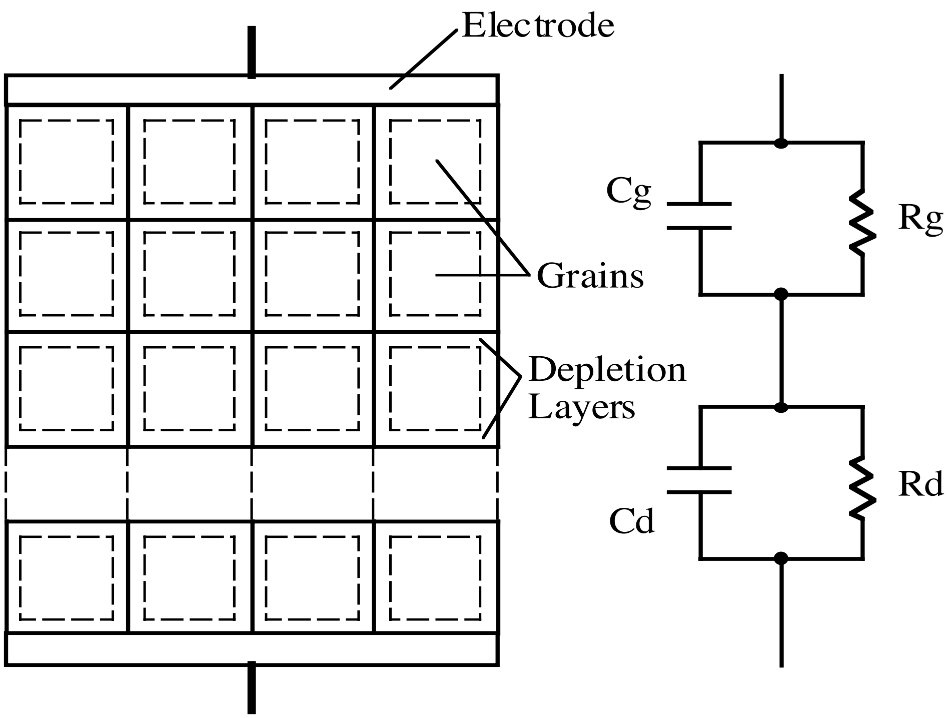
Schematic Model of SiC Ceramics with BeO Addition



Resistivity of SiC Ceramics (BeO addition) is higher than 10^{13} Ω·cm.

K.Maeda, et al., “Grain-boundary Effect in Highly Resistive SiC Ceramics with High Thermal Conductivity”, pp. 260-268 in Advances in Ceramics, ol. 7, Additives and Interfaces in Electronic Ceramics, ed. M.F.Yan and A.H.Heuer, American Ceramics Society, Columbus, OH., 1984.

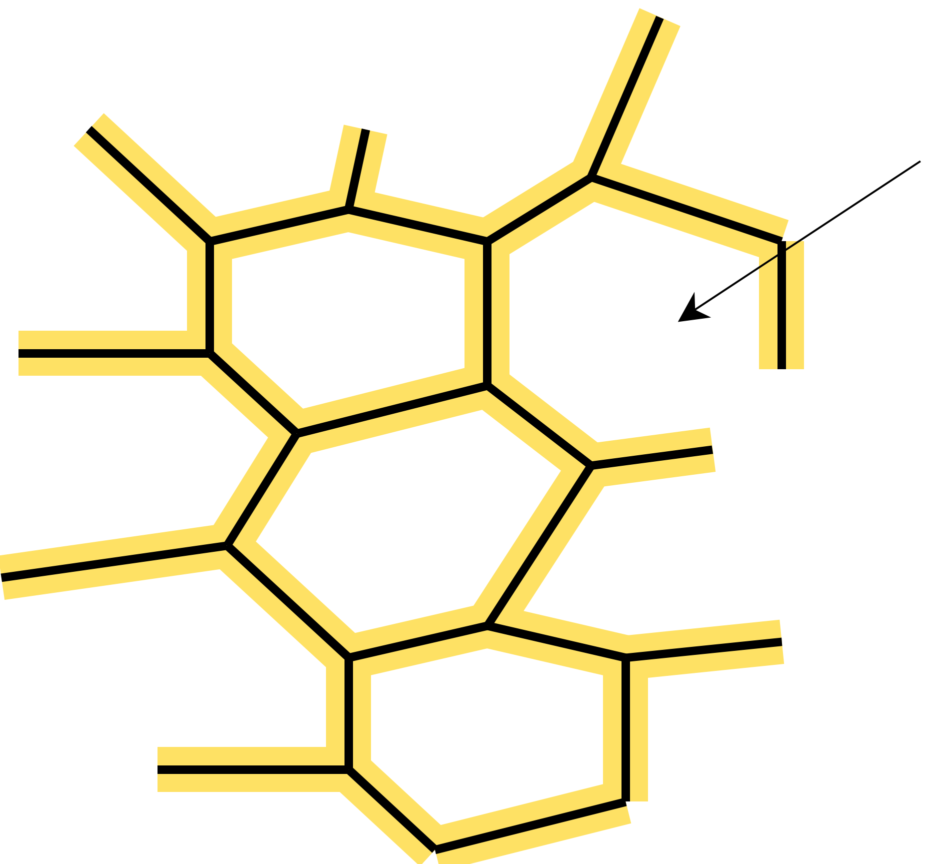
Two-layer Model and Equivalent Circuit



K. Maeda et al. (Hitachi co.) predicted dielectric properties of SiC ceramics using this equivalent circuit in 1985.

K.Maeda, et al., “Dielectric Behavior of SiC Ceramics with BeO Addition”, Extended Abstract of Electronics Div. 21-E-85, Annual Meeting, Am. Ceram. Soc., 1985.

Probably, SiC-B has a Similar Grain Structure



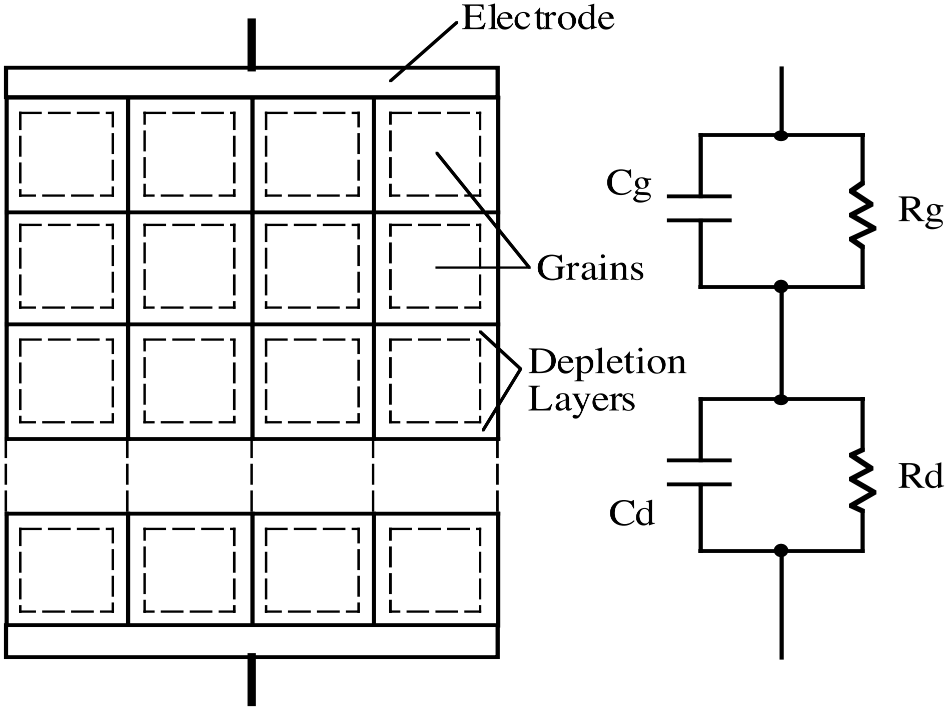
Grain : P-type Semiconductor
(Boron is doped ⇒ $\rho \ll 10\ \Omega\cdot\mathrm{cm}$)
ρ(Boron doped) < ρ(BeO doped) *

Resistivity of SiC-B is about 2×10^5 $\Omega\cdot\mathrm{cm}$.

ρ(Al doped) < ρ(B doped) < ρ(BeO doped) *

*Y.Takeda et al. "Effects of Additives on Thermal Conductivity and Electrical Resistivity of SiC Ceramics", Yogyo Kyokai-shi 95, [9],1987.
Ceramic Society of Japan.

Effective Permittivity (SiC-B) Calculated from Equivalent Circuit



Effective permittivity

$$\varepsilon_r' = \varepsilon_{r\infty} + \frac{\varepsilon_{r0} - \varepsilon_{r\infty}}{1 + \omega^2\tau^2} \qquad (2\text{-}1)$$

$$\varepsilon_r'' = \frac{(\varepsilon_{r0} - \varepsilon_{r\infty})\omega\tau}{1 + \omega^2\tau^2} + \frac{\sigma}{\varepsilon_0\omega} \qquad (2\text{-}2)$$

where σ is coductivity,

$\tau = R_g R_d (C_g + C_d)/(R_g + R_d)$

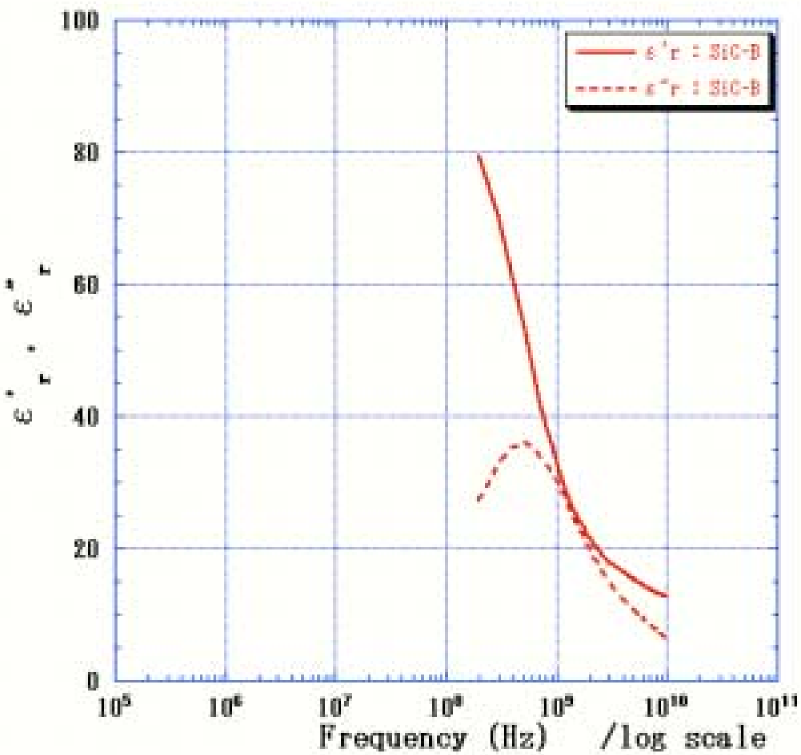
$R_g \ll R_d,\ C_g \ll C_d \Rightarrow \tau \cong R_g C_d$

$\frac{\sigma}{\varepsilon_0\omega} < 0.05$ above 0.2GHz. $\Rightarrow$ negligibly small

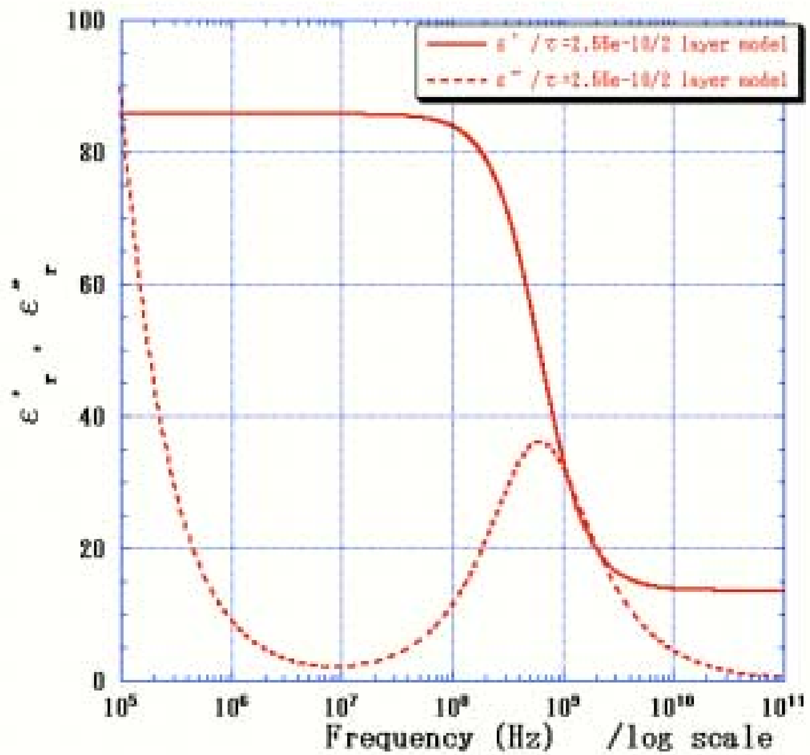
(2-1) and (2-2) $\Rightarrow$ Debye equations.

The ε″ behavior at lower frequencies is predicted by the model.

Permittivity (SiC-B) vs Frequency
Measured data



Permittivity (SiC-B) vs Frequency
Calculated from Equation (2-1) and (2-2).
Debye parameters(ε_{r0}, $\varepsilon_{r\infty}$ and τ) form the measurement data are used.



The ε″ behavior at lower frequency (< 0.2GHz) should be confirmed.

Conclusions

- Dielectric properties of SiC-B are explained by the structure of the grain and grain boundary.
- We can probably control the dielectric constant of SiC ceramics by using additives.
- We will use these results for the next future plan “Super KEKB”.

Thank you.