Thermal Conductivity of the Silicate Melts

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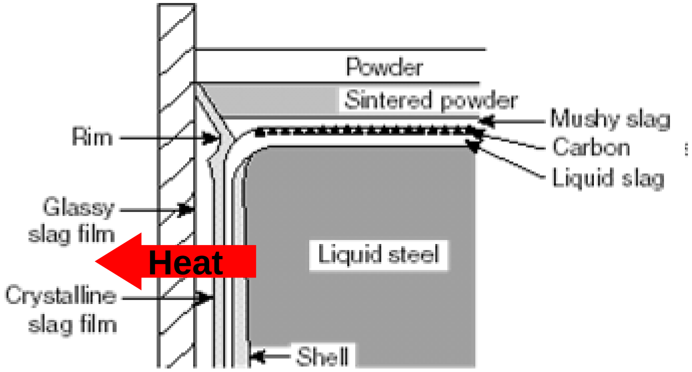
Agenda

- Introduction
  - **Thermal conductivity of liquid oxide**
  - **Previous studies and Objectives**
- Experimental
  - **Apparatus, Experimental procedure, Sample preparation**
- Results and Discussion
  - **Temperature and Composition dependence**
  - **Amphoteric behavior of Al_2O_3**
  - **Relationship of thermal conductivity to silicate structure**

Thermal Conductivity of Liquid Oxides

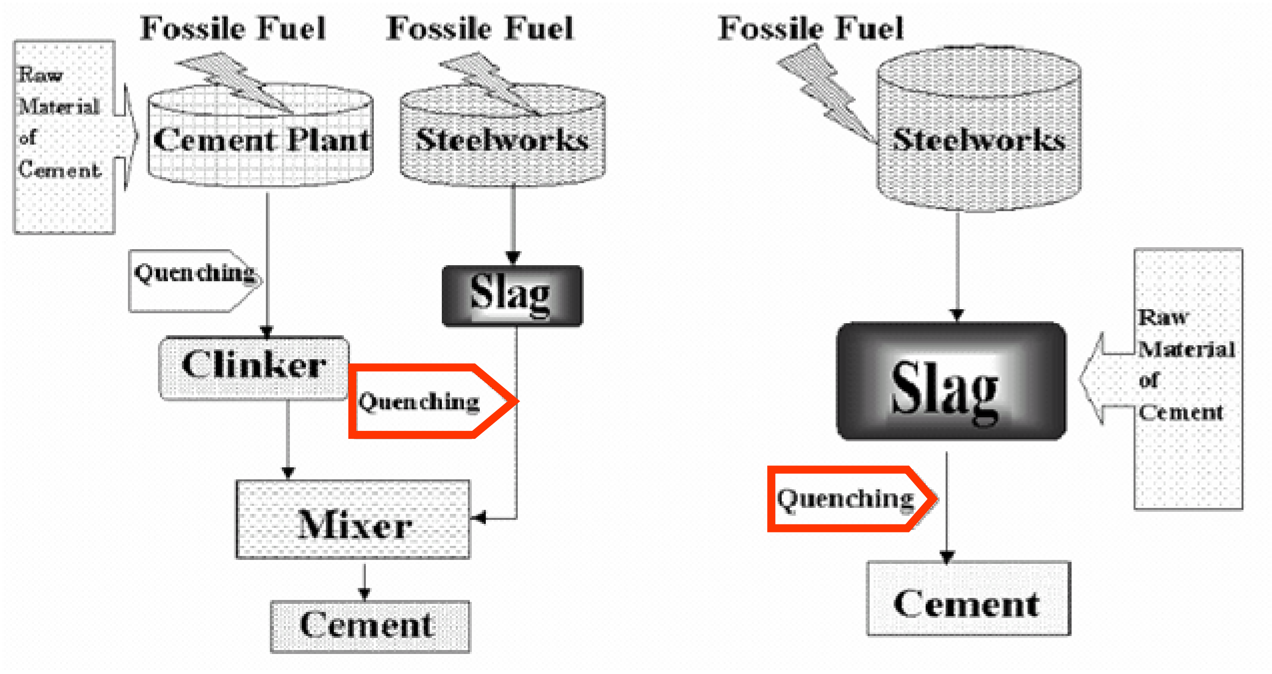
- **An important physical property in material production processes**
- **Thermal conductivity of liquid oxide in iron- and steelmaking**
  - Thermal conductivity of Na_2O-SiO_2 system (Nagata *et al.*)



Schematic representation of mold powder and slag film layer in continuous casting (M. Susa et al., Ironmaking and Steelmaking, 21(1994))

Thermal Application of Molten Slag

- Utilization of blast furnace slag and latent heat
- Optimization of BF slag recovery process



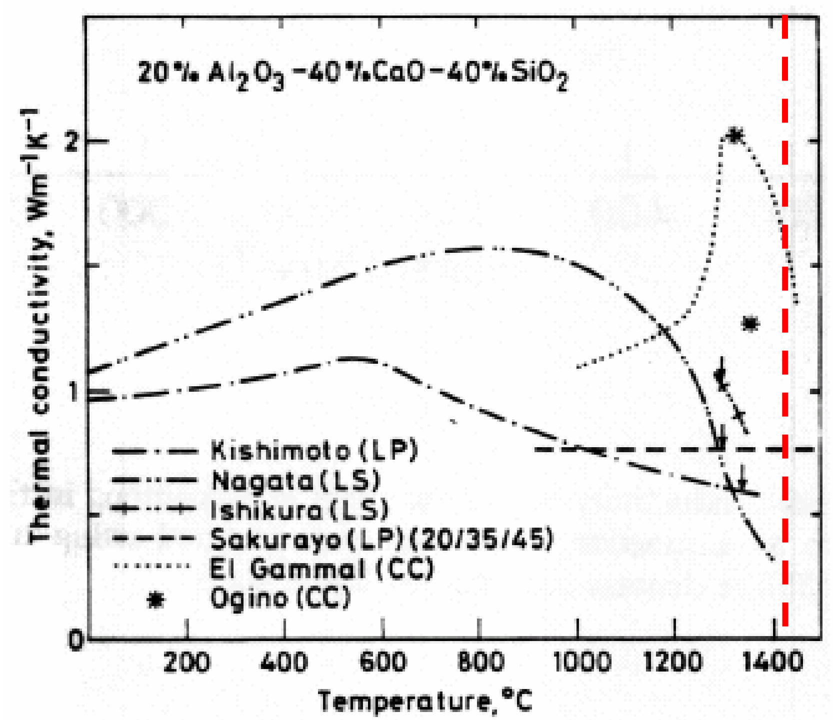
Introduction

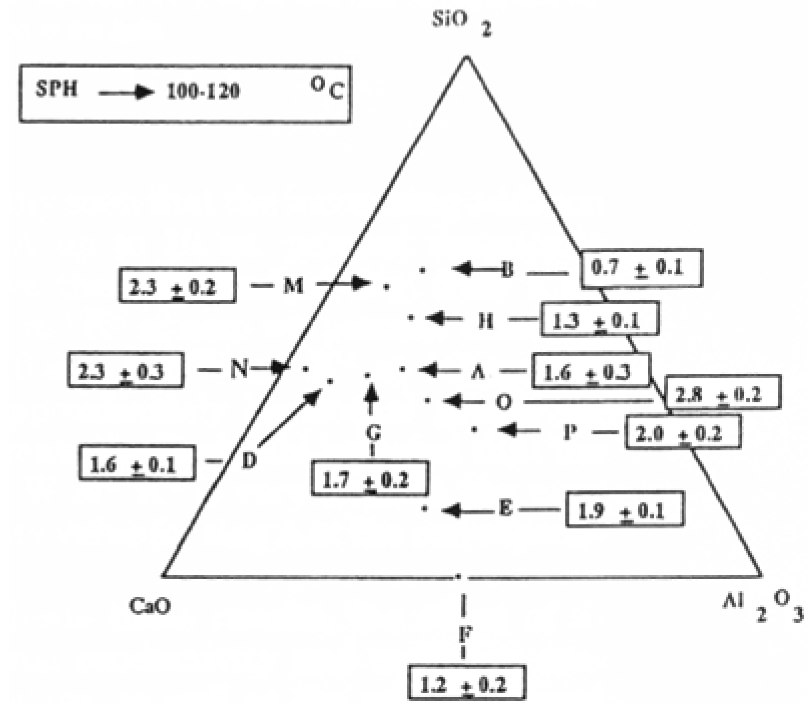
Previous Studies

COMPOSITION (mass%)	METHOD	TEMPERATURE RANGE (K)	THERMAL CONDUCTIVITY (W/mK)	AUTHORS
$40CaO-20Al_2O_3-40SiO_2$	hot wire method	373~1673	0.20~1.50	K. Nagata *et al.*
$25CaO-15Al_2O_3-60SiO_2$		373~1673	0.40~1.60	K. Nagata *et al.*
$40CaO-20Al_2O_3-40SiO_2$		1573	0.80~1.00	K. Nagata *et al*
$40CaO-20Al_2O_3-40SiO_2$		373~1673	0.50~1.70	M. Susa *et al.*
$40CaO-20Al_2O_3-40SiO_2$	laser flash method	273~1623	0.70~1.20	M. Kishimoto *et al.*
$45CaO-15Al_2O_3-40SiO_2$		273~1673	0.60~1.20	M. Kishimoto *et al.*
$50CaO-15Al_2O_3-35SiO_2$		273~1673	0.50~1.00	M. Kishimoto *et al.*
$50CaO-15Al_2O_3-35SiO_2$		1273~1723	0.50	T. Sakuraya *et al.*
$35CaO-20Al_2O_3-45SiO_2$		1273~1723	0.70~0.80	T. Sakuraya *et al.*
$40CaO-20Al_2O_3-40SiO_2$	radial heat flow	1573~1623	1.10~2.00	K. Ogino *et al.*
$40CaO-20Al_2O_3-40SiO_2$		1273~1673	1.00~2.00	T. El Gammal *et al.*
$CaO-Al_2O_3-SiO_2$ system		m.p.+100	0.70~2.80	D. Sommerville *et al.*

→ limitation in the compositions and temperature

Previous Studies



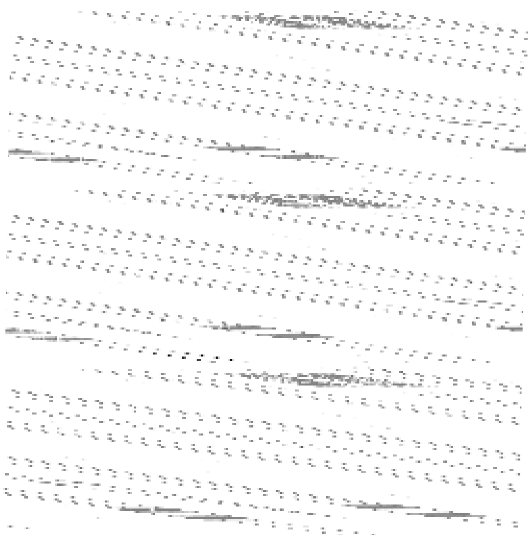


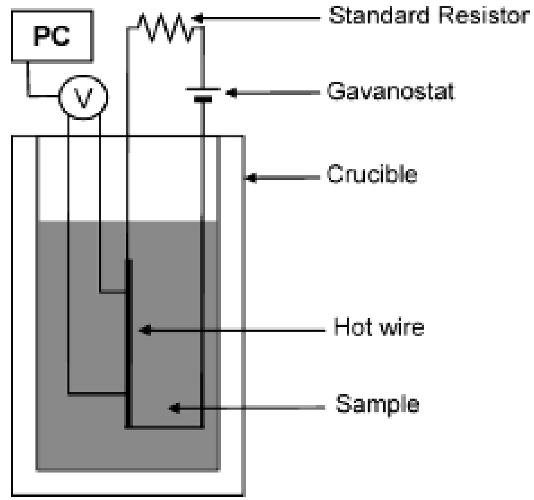
Results of thermal conductivity measurement of the CaO-Al_2O_3-SiO_2 system (left) after Slag Atlas and (right) by D.Sommerville et al, Trans. of the ISS,1991

→ reliable thermal conductivity data in pure liquid region: insufficient

Measurement of Thermal Conductivity

- Measurement methods for liquid oxide
  - Stationary methods
  - Non-stationary method
    - Laser flash method, Hot-wire method





Objectives

- Measurement the thermal conductivity of the $CaO\text{-}Al_2O_3\text{-}SiO_2$ system using hot-wire method from liquidus temperature to 1873K

- Better understanding on the relationship between the thermal conductivity and silicate structure from its temperature and composition dependences

Experimental

Hot-wire Method

- Equation for thermal conductivity

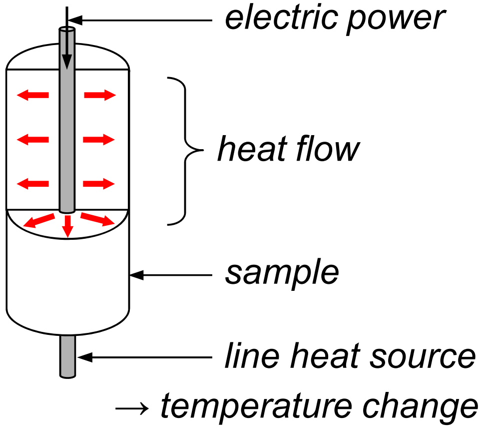
$$\lambda = \frac{Q}{4\pi} \Big/ \frac{\partial(\Delta T)}{\partial(\ln t)}$$

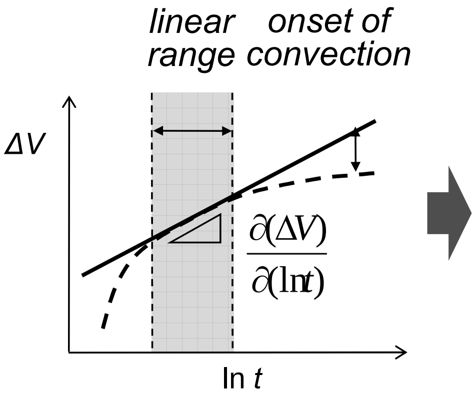
Q : Heat generation of unit length of hot-wire

γ : Euler constant

  – slope ΔT against $\ln t$

- Minimization of the effects of convection and radiation

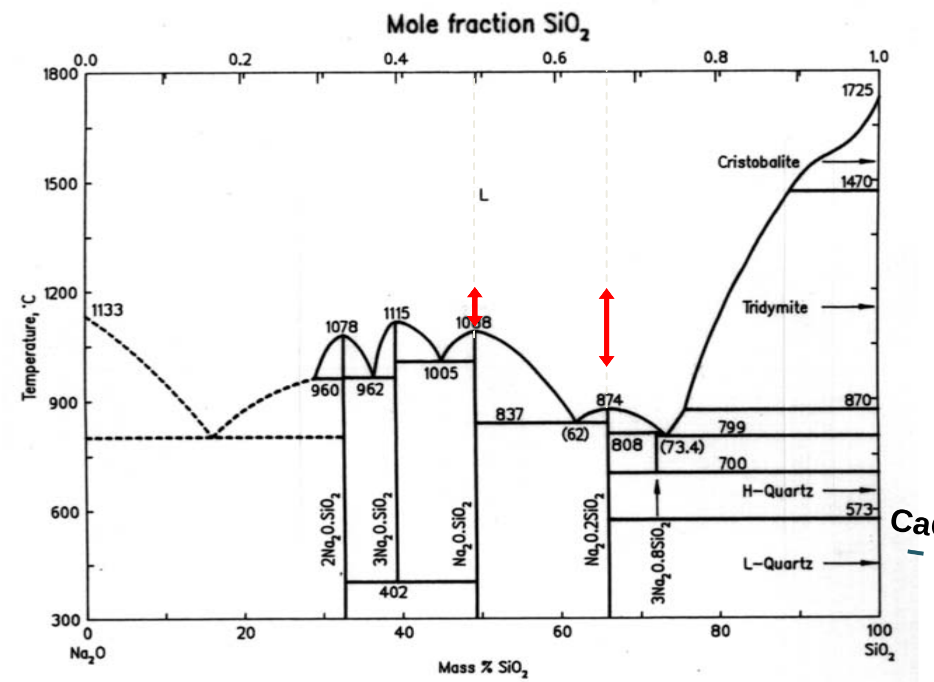




Experimental

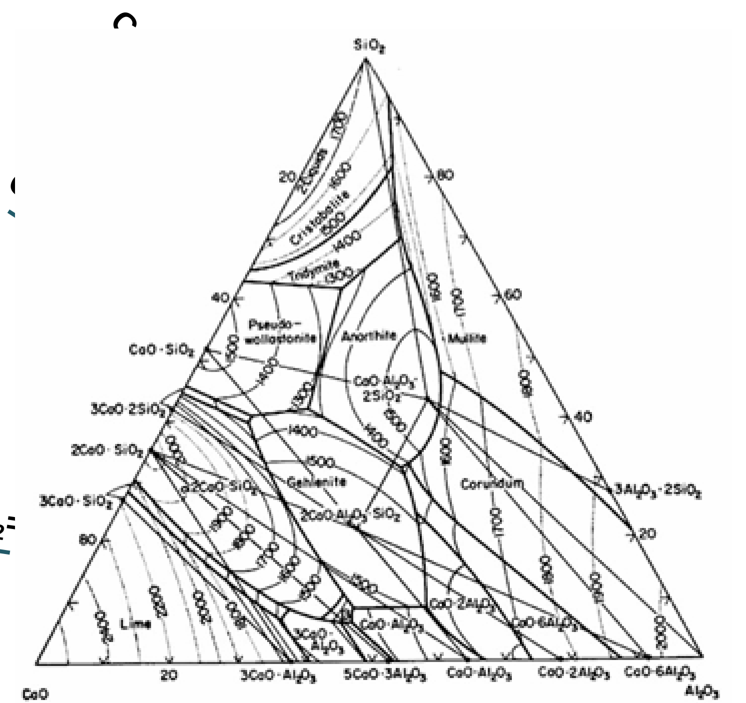
Sample Preparation

weighing, mixing → pre-melting at 1873K for 20min. → crushing to powder



Phase diagram of Na_2O-SiO_2 system and measurement range

CaO/SiO_2=



ternary phase diagram of the CaO-Al_2O_3-SiO_2 system

Experimental

Experimental Procedure

Measurement

Supply constant power (1.5A) to hot-wire

Measure temperature change of hot-wire

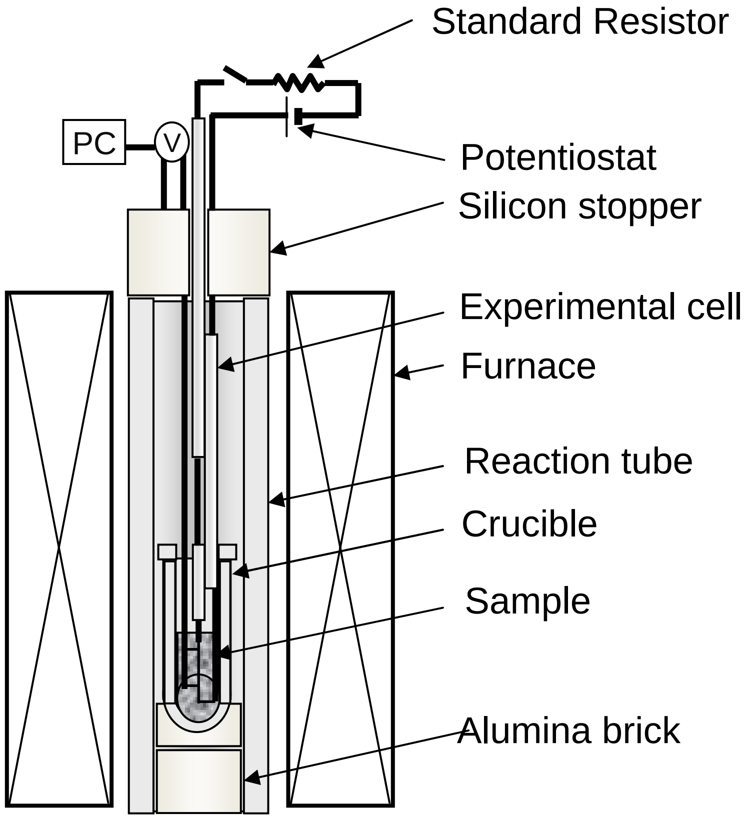
Plot ΔT against ln t

Calculate thermal conductivity

Analysis

SiO_2: gravimetry., Others: ICP-AES

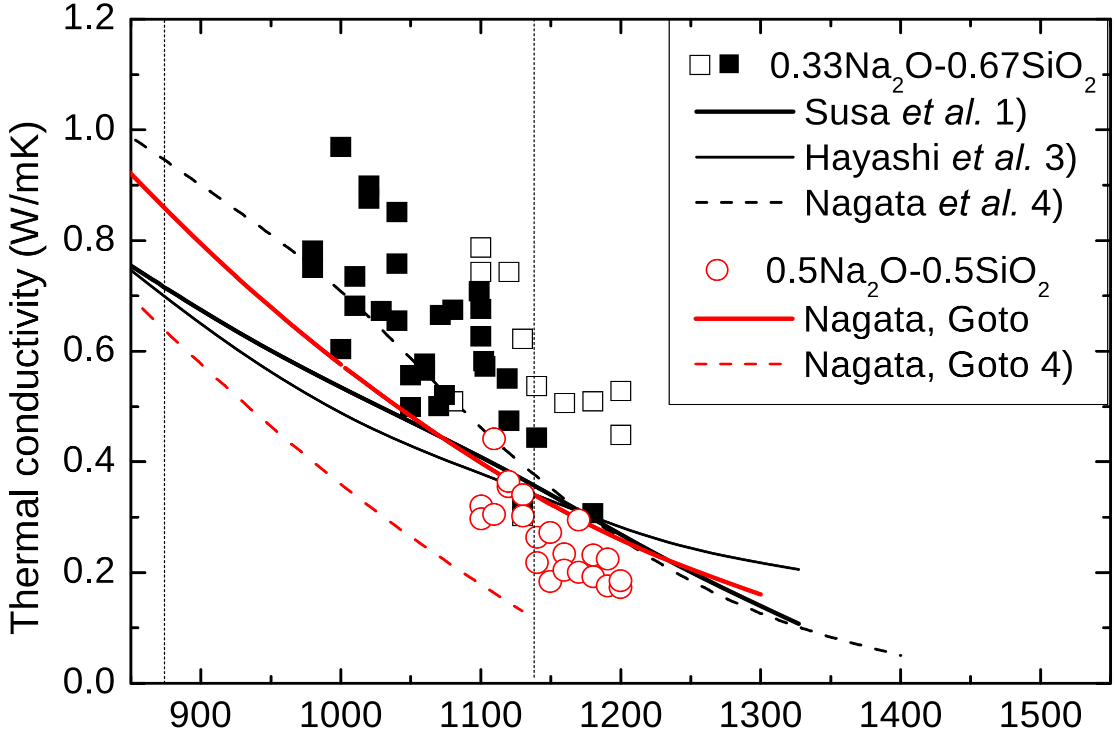
Crucible	Alumina or Pt-10%Rh
Temp.	L.T.~1873K, every 50K



Schematic diagram of hot wire measurement apparatus

Thermal Conductivity and Temperature

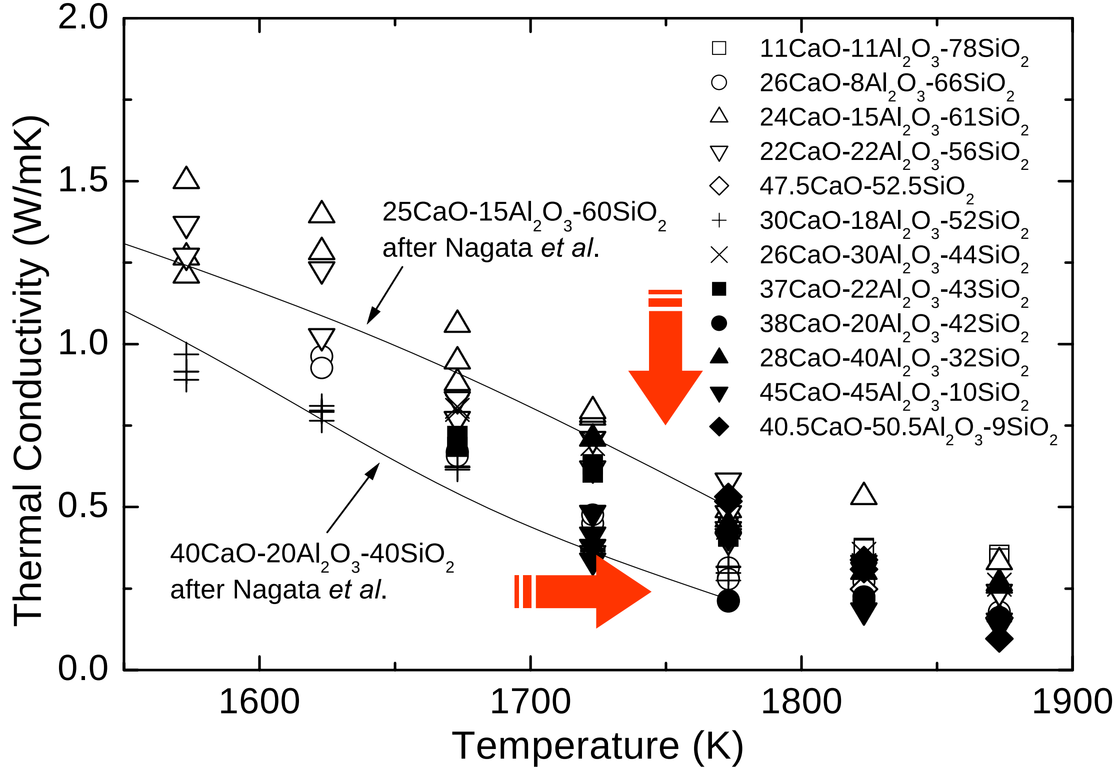
- The Na_2O-SiO_2 system



Thermal conductivities of the Na_2O-SiO_2 system as a function of temperature

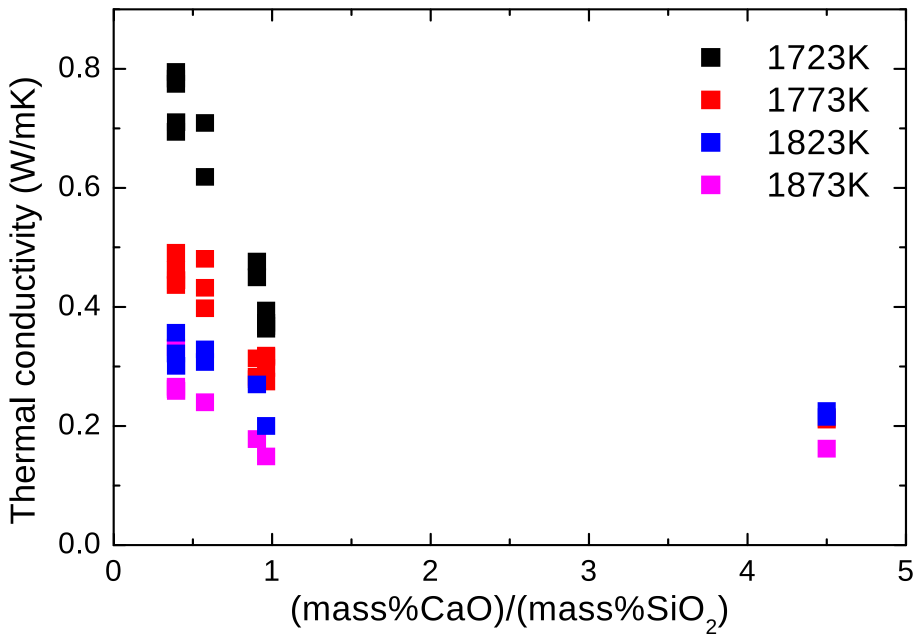
Thermal Conductivity and Temperature

- The $CaO-Al_2O_3-SiO_2$ system



Thermal conductivities of the $CaO-Al_2O_3-SiO_2$ system as a function of temperature

Thermal Conductivity and Basicsity



Relationship between thermal conductivity and CaO/SiO_2 ratio

$$\frac{\text{mass\%CaO}}{\text{mass\%SiO}_2}$$: basicity

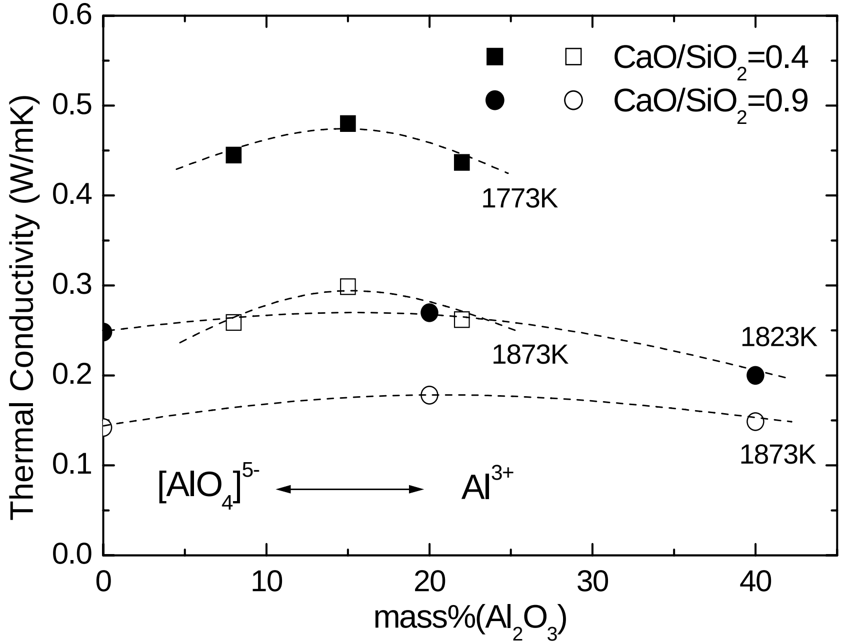
acid-side: basicity ∝ thermal conductivity

basic-side: relatively high thermal conductivity

➡ **influence of Al_2O_3 ?**

Results and Discussion

Amphoteric Behavior of Al_2O_3



Dependence of thermal conductivity on Al_2O_3 content at constant CaO/SiO2 ratios

- **Maximum value in thermal conductivity with Al_2O_3 addition**
- **Change in the role of Al_2O_3 between network former and network modifier**

Silicate Structure and Temperature

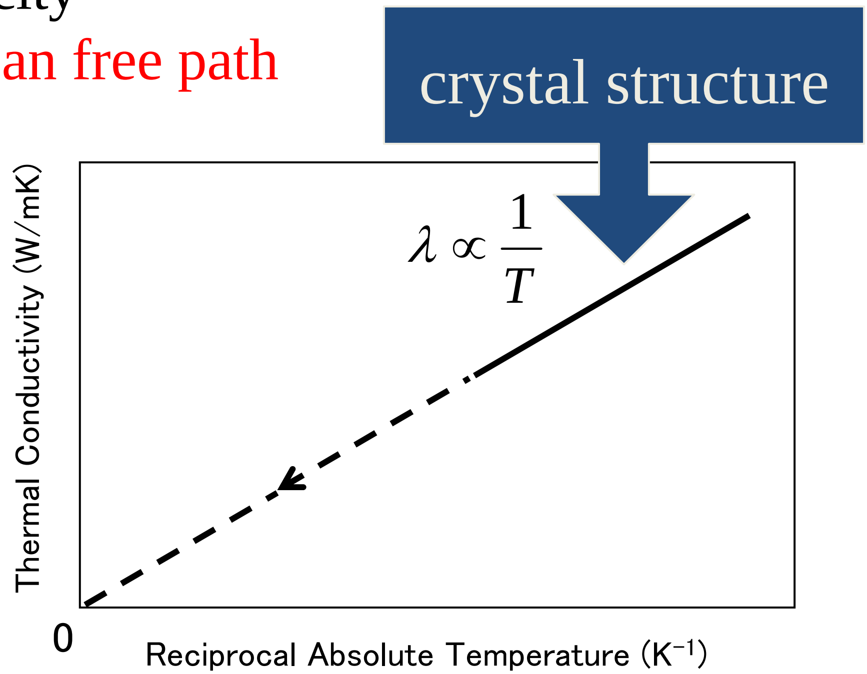
- Debye's expression for thermal conductivity

$$\lambda = \frac{Cvl}{3}$$

C: heat capacity
v: sound velocity
l: phonon mean free path

in crystalline materials

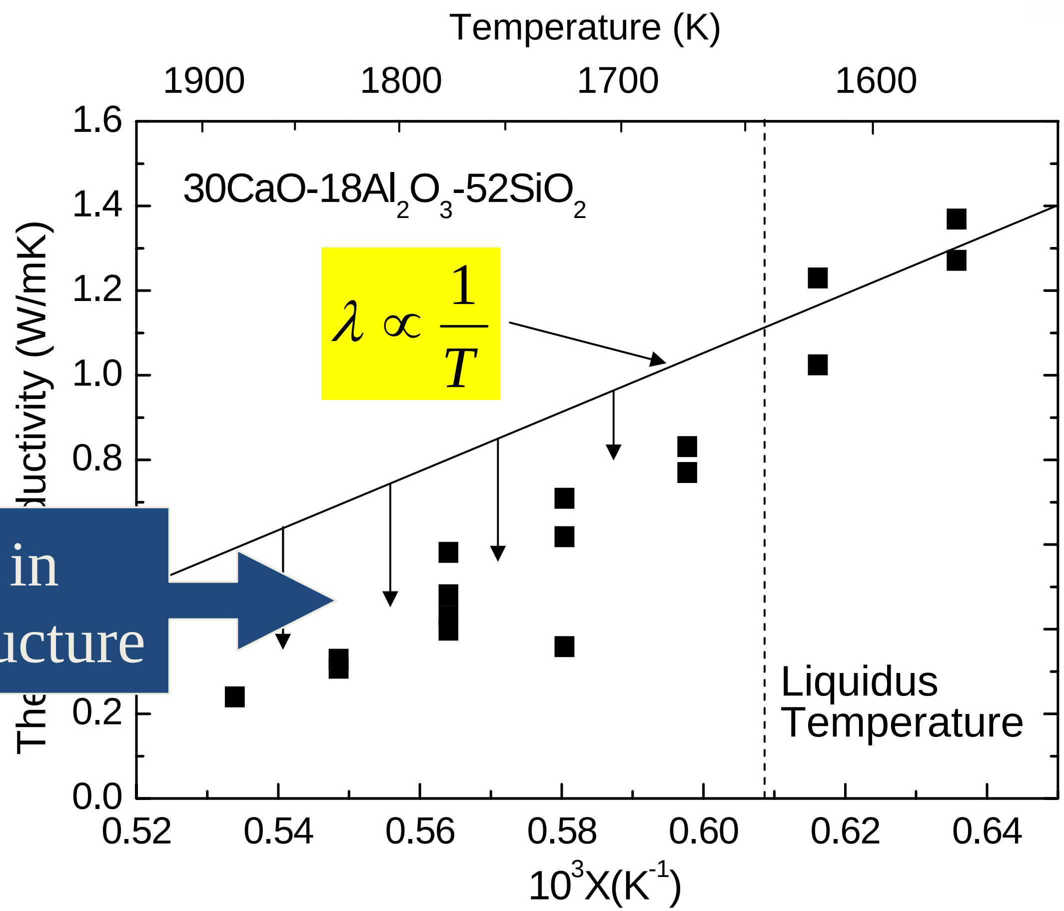
$$l \propto \frac{1}{T} \quad , \quad \lambda \propto \frac{1}{T}$$



Results and Discussion

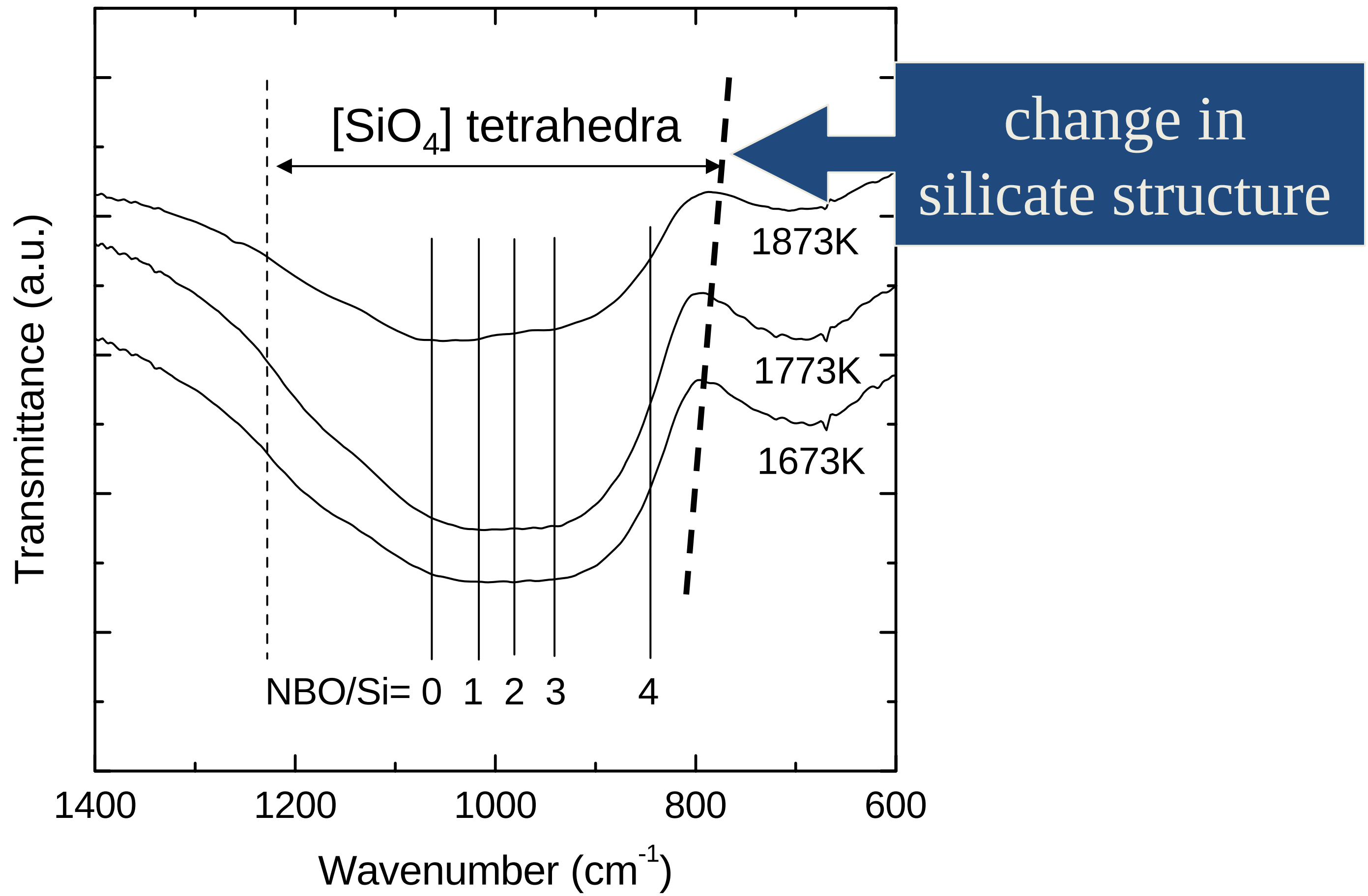
Silicate Structure and Temperature

change in
silicate structure



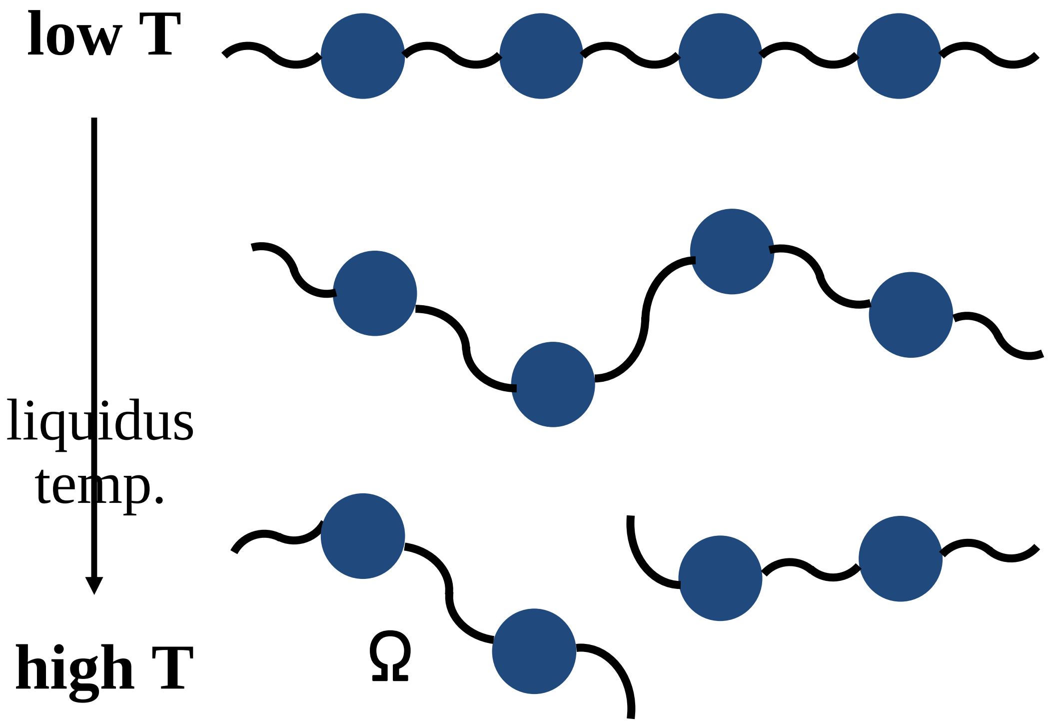
Dependence of thermal conductivity of 30%CaO-18%Al$_2$O$_3$-52%SiO$_2$ on the inverse absolute temperature

Silicate Structure and Temperature



IR transmittance of 30%CaO-18%Al_2O_3-52%SiO_2

Silicate Structure and Temperature



thermal vibration ↑

$$l \propto \frac{1}{T}$$

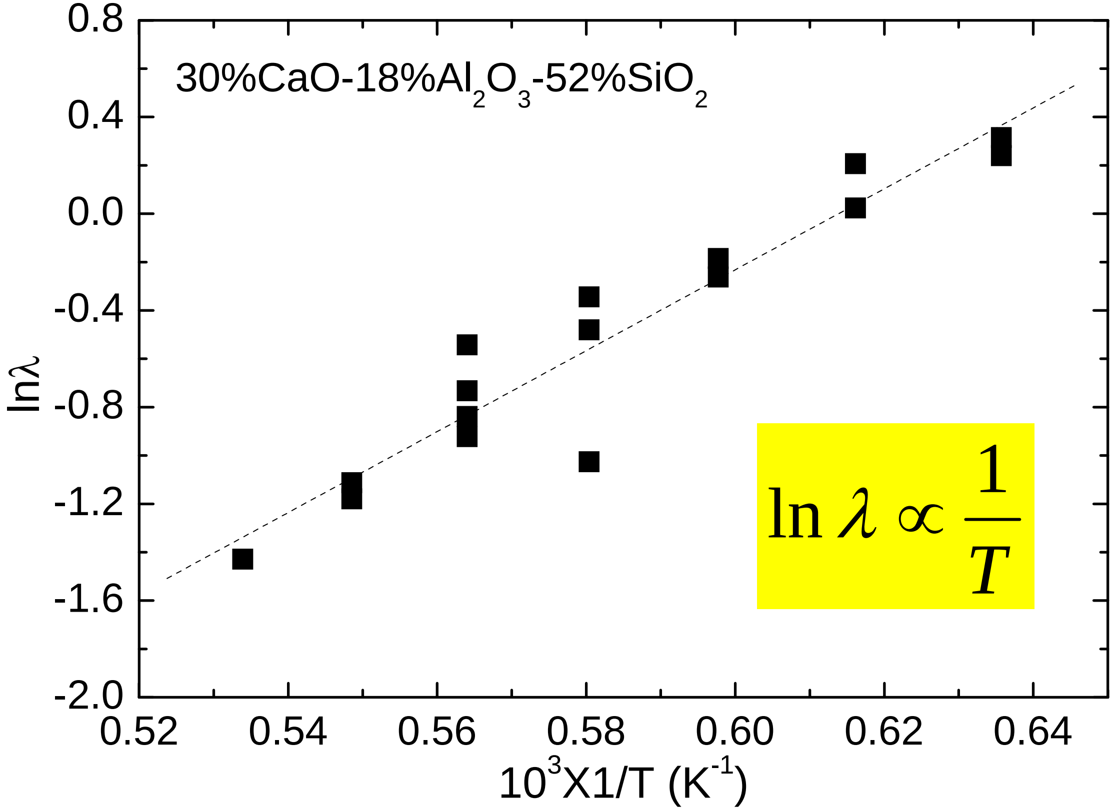
interaction volume ↓

$$l \propto \Omega$$

- Bond breakage depends the bonding energy
- A broken bond divides the interaction volume

$$\lambda \propto \exp\left(\frac{1}{T}\right)$$

Silicate Structure and Temperature



Dependence of logarithm of thermal conductivity of 30%CaO-18%Al_2O_3-52%SiO_2 on the reciprocal absolute temperature

Conclusions

- **The thermal conductivity of the Na_2O-SiO_2 and CaO-Al_2O_3- SiO_2 system was measured by hot-wire method in their pure liquid region**
- **The thermal conductivity decrease in more basic silicate, and as temperature rises. And amphoteric behavior of Al_2O_3 was observed in the ternary system**
- **Temperature dependence deviates from the linearity at higher temperature than liquidus temperature. The change in silicate structure may cause this disagreement.**