第四章 电子陶瓷的基本性质

早期的电子陶瓷主要用作绝缘材料-力学/热学性质。

近年来，电子陶瓷已广泛用作功能转换材料——力学、热学、电学、磁学、声学及光学等性质。

重点介绍力、热、电、光性质

§4.1 电子陶瓷的密度

Many applications of ceramics are based unique physical properties.

Space shuttle thermal protection tiles, for example, require ultralight weight, high temperature resistance, high thermal shock resistance, and low conduction of heat.

Density is an important based physical properties.

Density(ρ) is a measure of the mass (m) per unit volume (V) of a material and is reported in units such as grams per cubic centimeter or pounds per cubic inch.

The term density can be used in various ways:

1. Crystallographic density:

the ideal density of a specific crystal structure calculated from chemical composition data and from inter-atomic spacing data obtained by x-ray diffraction

2. Theoretical density:

the density of a material that contains zero microstructural porosity (takes into account multiple phases, defect structures, and solid solution)

3. Bulk density

the measured density of a bulk ceramic body (includes all porosity, lattice defects, and phases)

4. Specific gravity:

the density of a material relative to the density of an equal volume of water at 4 ºC

(usually based upon crystallographic or theoretical density)

§4.1.1 Crystallographic density:

The crystallographic density (CD) is calculated by dividing the mass (weight) of a unit cell of the material by the volume of the unit cell.

$$CD = \frac{\text{total mass of atoms in a unit cell}}{\text{volume of a unit cell}}$$

Exampl: 4.1 Estimate the crystallographic density (CD) of copper.

Cal: Copper has a FCC structure. Each unit cell contains four atoms (one eighth each of eight corner atoms plus one half each of six face-centered atoms)

$$\because \text{Weight per uint cell} = \frac{\text{(Number of atoms per unit cell)(atomic weight)}}{\text{(Avogadro's number)}}$$

$$\therefore \text{Weight per uint cell} = \frac{(4)(63.54\text{g/mol})}{(6.022\times 10^{23}\text{atoms/mol})} = 4.22\times 10^{-22}\text{g}$$

The atomic radius (*r*) for Cu is 1.278 Å, so the length of the edge (a) of the unit cell is:

$$\text{Q}\ a=\frac{4r}{\sqrt{2}}=\frac{4\times1.278}{\sqrt{2}}=3.61\text{Å}=3.61\times10^{-8}\,\text{cm}$$

$$\therefore V_{\text{unit cell}}=(a)^3=(3.61\times10^{-8})^3=4.70\times10^{-23}\,\text{cm}^3$$

$$\text{CD}=\frac{m}{V}=\frac{4.22\times10^{-22}\ g}{4.70\times10^{-23}\,\text{cm}^3}=8.98\ g/cm^3$$

The density of copper is listed as 8.92g/cm^3 in the *Handbook of Chemistry.*

Elements with low atomic weight such as H, Be, C, N, O, Si and B result in materials with low crystallographic density.

However, we note:

The CD of diamond is 3.52g/cm^3;

The CD of graphite is 2.27g/cm^3;

Polymorphs of other materials have a density difference, but not quiet as large.

For example,

the quartz, tridymite（鳞石英）,

and cristobalite（方石英） polymorphs of SiO_2 have crystallographic densities,

respectively, of 2.65, 2.19 and 2.33 g/cm^3.

§4.1.2 Bulk Density:

Most ceramics contain more than one crystalline phase and often a noncrystalline phase.

In addition, there is porosity present in the microstructure.

So, the crystallographics density does not adequately characterize such as a mixed-phase material.

The bulk density (BD) is calculated as follows:

$$BD = \frac{\text{mass}}{\text{bulk volume}}$$

$$= \frac{\text{mass}}{\text{bulk volume} + \text{bulk porosity}}$$

The bulk density of a complex shape for which no simple geometric equation is available is measured using Archimedes's principle, where the difference in the weight of the shape in air compared to the weight suspended in water permits calculation of the volume.

Parts with no surface-connected porosity can be immersed directed in water.

Parts containing surface-connected porosity must be either coated with a wax or other impervious material of known density or boiled as defined in American Society for Testing and Materials Specification ASTM C373.

The procedure of ASTM C373 involves first measuring the dry weight D.

The part is then boiled in water for 5h and allowed to cool in the water for 24h.

The wet weight in air W and the wet weight suspended in water S are then measured.

The following can then be calculated:

$$\text{Exterior Volum } V = \frac{W - S}{\rho_{air}}$$

$$BD = \frac{D}{V}$$

$$\text{Apparent porosity } P = \frac{W - D}{V}$$

$$\text{Volume of impervious material} = D - S$$

$$\text{Apparenty specific gravity } T = \frac{D}{D - S}$$

$$\text{Water absorption } A = \frac{W - D}{D}$$

§4.1.3 Theoretical Density

For many application it is desirable to produce a ceramic material that contains minimum open and closed porosity.

The pore-free ceramic would represente the maximum bulk density achievable for the specific composition and is referred to as the theoretical density.

Theoretical density can be calculated if the crystallographic density and volume fraction of each solid phase in the microstructure are known.

Example 4.2

A ceramic composite material consists of 30 volume% SiC whiskers in an Al_2O_3 matrix. Estimate the TD if SiC has a CD of 3.22 g/cm^3 and Al_2O_3 has a CD of 3.95 g/cm^3.

$$\text{Q TD} = (\text{Volume fraction SiC})(\text{CD SiC})$$

$$+ (\text{Volume fraction } Al_2O_3)(\text{CD } Al_2O_3)$$

$$\therefore \text{TD} = (0.3)(3.22\,\text{g/cm}^3) + (0.7)(3.95\,\text{g/cm}^3)$$

$$= 0.966 + 2.765 = 3.731\,\text{g/cm}^3$$

Example 4.3

A mixture of 30 volume% SiC whiskers and 70 volume% Al_2O_3 powders is hot pressed. The measured bulk density is 3.65 g/cm^3 .

1. What is the percent theoretical density?

2. How much porosity is present?and Al_2O_3 has a CD of 3.95 g/cm^3.