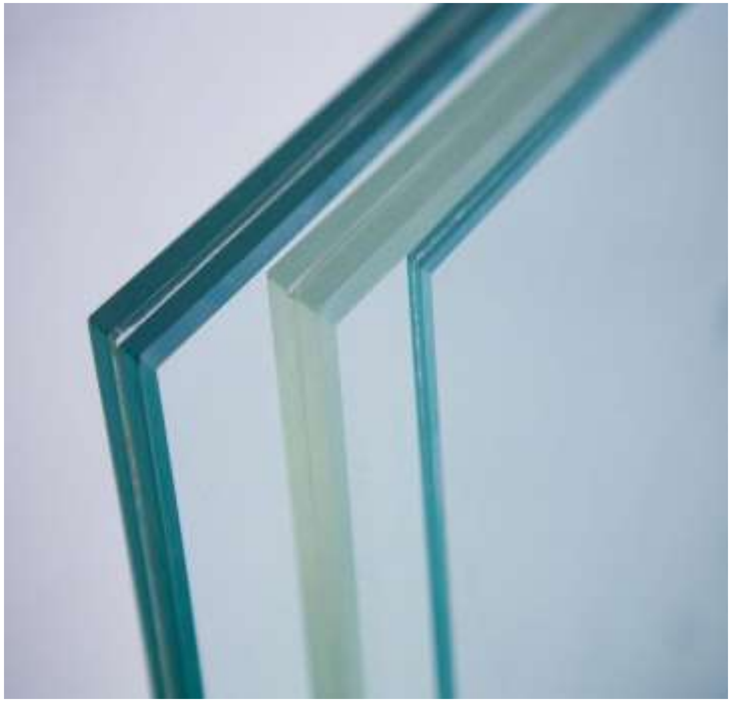
Lecture 6

Ceramics and glass



Learning Objectives

- What are ceramics?
- Classification of ceramics
- Thermal Properties of ceramics
- Optical Properties
- Mechanical Properties
- Electrical Properties
- Ceramic Processing
- What are glasses and what are their uses?
- General properties of glass
- Raw materials of glass
- Types of glasses
- Glass ceramics

Ceramics

- **Ceramics**- are compounds (Mixture) of **metallic** and **nonmetallic** elements
  - Traditional ceramics: tiles, brick, sewer pipes, and pottery.
  - Industrial ceramics (engineering ceramics): used in automotives, aerospace, and turbines

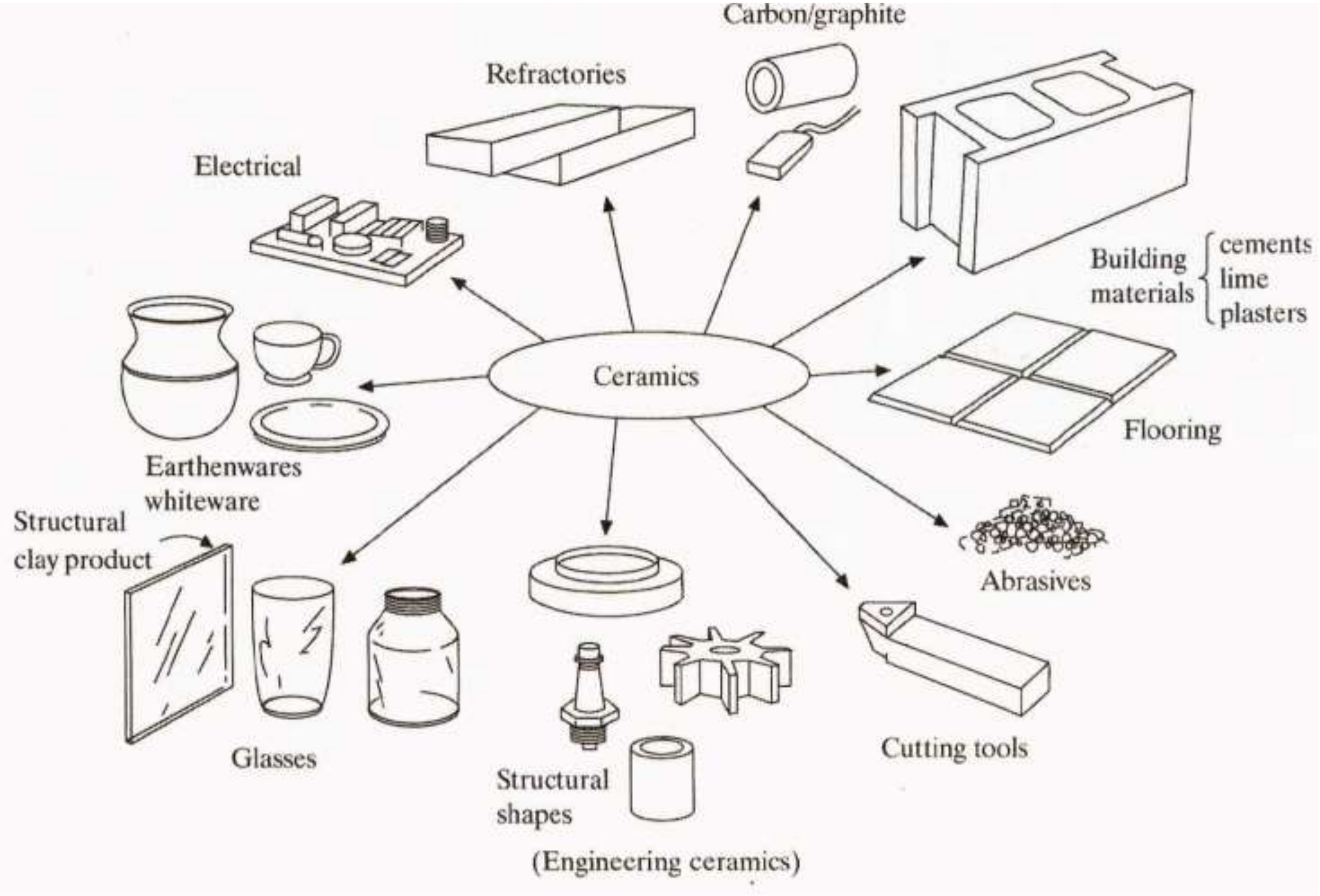
Raw Materials- **clay** (oldest, fine-grained sheet-like structure), **kaolinite** (white clay made of silicate of aluminum, slippery and moldable characteristics), **flint** (composed of fine silica), **feldspar** (crystalline minerals with aluminum silicates and potassium, sodium, or calcium)

Porcelain- white ceramic made of kaoline, quartz, and feldspar.

Applications

- Pottery, brick, tile, glass, ovenware, magnets, refractories, cutting tools.
- Furnace linings and tiles for space shuttle due to high resistance to heat.
- Superconductivity applications.

Spectrum of Ceramics uses



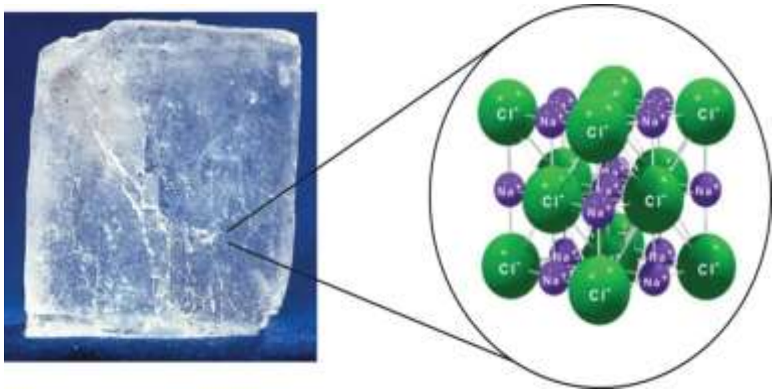
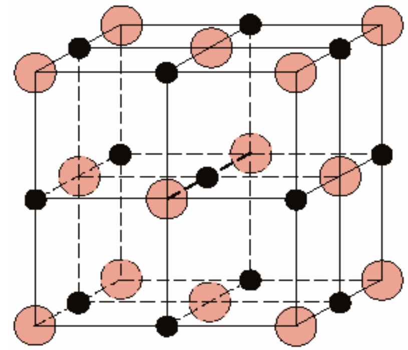
Ceramics crystal structure

ceramics that are predominantly **ionic** in nature have **crystal** structures. The crystal structure for a given ceramic depends upon two characteristics:

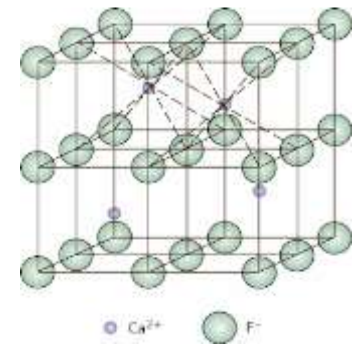
1. the magnitude of electrical charge on each component ion, recognizing that the overall structure must be **electrically neutral**

2. the relative size of the cation(s) and anion(s),which determines the type of interstitial site(s) for the cation(s) in an anion lattice

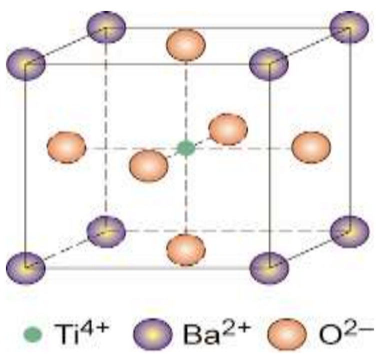
Examples of crystal structure

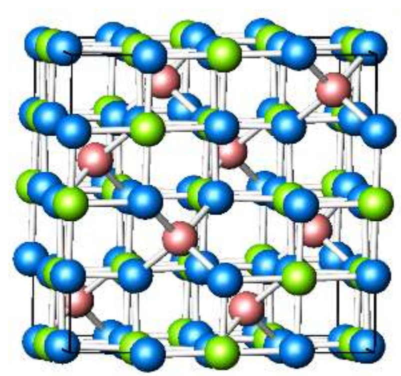
Rock salt structure (NaCl)



Fluorite structure (CaF2)



Perovskite structure (BaTiO3)



Spinel structure (MgAl2O4)

Imperfection in Ceramics

- Include point defects and impurities
- Charge neutral defects include the **Frenkel defects** (a vacancy- interstitial **pair of cations**) and **Schottky** defects (a pair of nearby **cation and anion** vacancies)
- Defects will appear if the charge of the **impurities is not balanced**

Properties of Ceramics

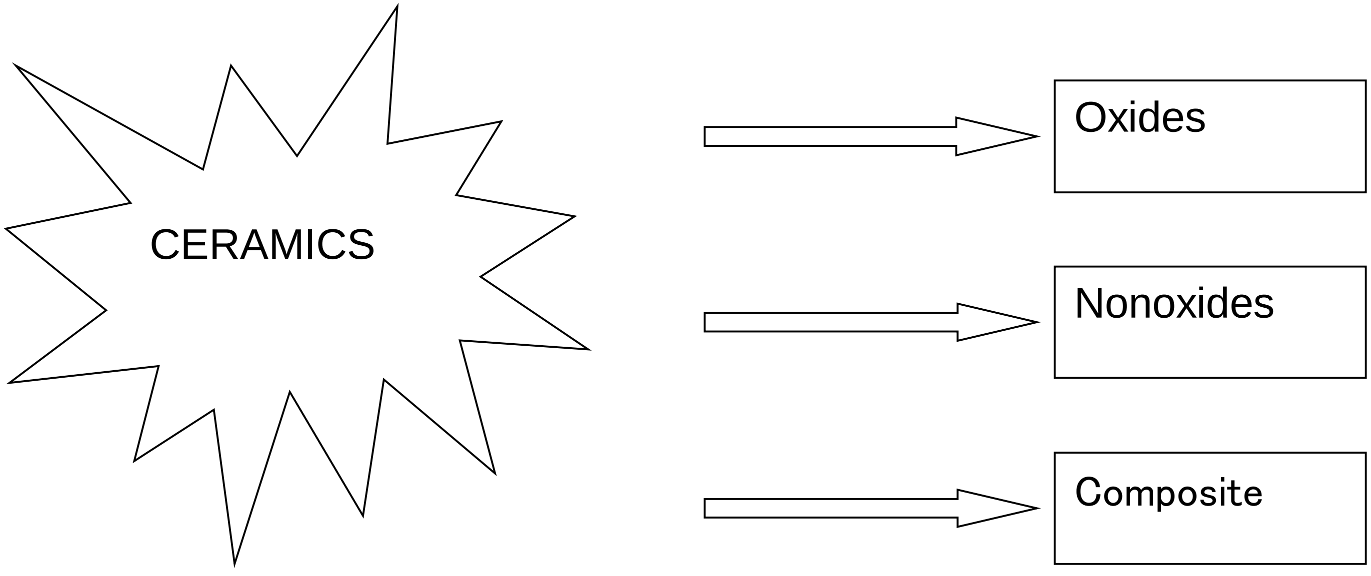
- **Extreme hardness**
  - High wear resistance
  - Extreme hardness can reduce wear caused by friction
- **Corrosion resistance**
- **Heat resistance**
  - Low electrical conductivity*
  - Low thermal conductivity
  - Low thermal expansion
- **Low ductility**
  - Very brittle
  - High elastic modulus
- **Low toughness**
- **Low density**
  - Porosity affects properties
- High strength at elevated temperatures

- *(Except ceramics used in medical field as a superconducting magnet in MRI scanners).

General comparison of materials

Property	*Ceramic*	*Metal*	*Polymer*
Hardness	Very High	Low	Very Low
Elastic modulus	Very High	High	Low
Thermal expansion	High	Low	Very Low
Wear resistance	High	Low	Low
Corrosion resistance	High	Low	Low

Classification of ceramics



- ***Oxides:*** Alumina, zirconia
- ***Non-oxides:*** Carbides (**$CaC2$**) , borides, nitrides, silicides
- ***Composites:*** Particulate reinforced, combinations of oxides and non-oxides

Classification of ceramics cont.

- ***Oxide Ceramics:***

➢ Oxidation resistant

➢ chemically inert

➢ electrically insulating

➢ generally low thermal conductivity

➢ slightly complex manufacturing

➢ low cost for alumina

➢ more complex manufacturing

higher cost for zirconia.

Classification of ceramics cont.

- ***Non-Oxide Ceramics:***
  - Low oxidation resistance
  - extreme hardness
  - chemically inert
  - high thermal conductivity
  - electrically conducting
  - manufacturing and high cost.

Silicon carbide cermic foam filter (CFS)

Classification of ceramics cont.

- ***Ceramic-Based Composites*:**
  - Toughness
  - low and high oxidation resistance (type related)
  - variable thermal and electrical conductivity
  - complex manufacturing processes
  - high cost.

Ceramic Matrix Composite (CMC) rotor

Traditional Ceramics

- the older and more generally known types (porcelain, brick, earthenware, etc.)
- Based primarily on natural raw materials **of clay and silicates**
- **Applications;**

  building materials (brick, clay pipe, glass)

  household goods (pottery, cooking ware)

  manufacturing (abrasives, electrical devices, fibers)

Advanced Ceramics

- ✓ Industrial ceramics (engineering ceramics): used in **automotives, aerospace, and turbines**
- ✓ have been developed over the past half century
- ✓ Include artificial raw materials, exhibit specialized properties, require more sophisticated processing
- ✓ Applied as thermal barrier coatings to protect metal structures, wearing surfaces,
- ✓ Engine applications (silicon nitride (Si_3N_4), silicon carbide (SiC), Zirconia (ZrO_2), Alumina (Al_2O_3))

bioceramic implants

Physical Properties

- Thermal conductivity ranges and is related to porosity
-
- **Thermal cracking-** when a small piece or layer breaks off, tends to be lower with a combination of low thermal expansion and high thermal conductivity

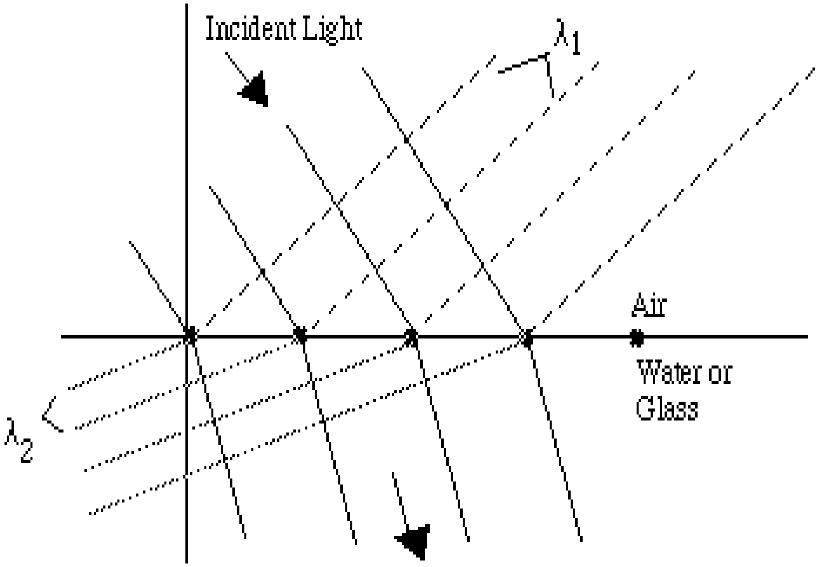
- **Anisotropy of thermal expansion-** when thermal expansion ranges with different directions through the ceramic, causes thermal stresses that lead to cracking

- **Bioceramics**- used as biomaterials for human joints because of strength and inertness, they create a structurally strong bond

Optical Properties of Ceramics

Refraction

Light that is transmitted from one medium into another, undergoes refraction.



Refractive index, (n) of a material is the ratio of the speed of light in a vacuum ($c = 3 \times 10^8$ m/s) to the speed of light in that material.

$$n = c/v$$

Electrical properties of Ceramics

- Electrical conductivity of ceramics varies with
  - ❖ *The Frequency of field applied effect*
- charge transport mechanisms are frequency dependent.
  - ❖ *The temperature effect*
- The *activation energy* needed for charge migration is achieved through thermal energy and immobile charge career becomes mobile.
- Most of ceramic materials are **dielectric**. (materials, having very low electric conductivity).
- ***Dielectric ceramics*** are used for manufacturing capacitors, insulators and resistors.

Dynamic random-access memory (**DRAM**) is a type of random-access memory that stores each bit of data in a separate capacitor within an integrated circuit

Glass

Glass is an amorphous, hard, brittle, transparent or translucent, obtained by fusing a mixture of a number of **metallic silicates, most commonly Na, K, Ca and Pb".** It possesses no sharp melting point, crystalline structure and definite formula.

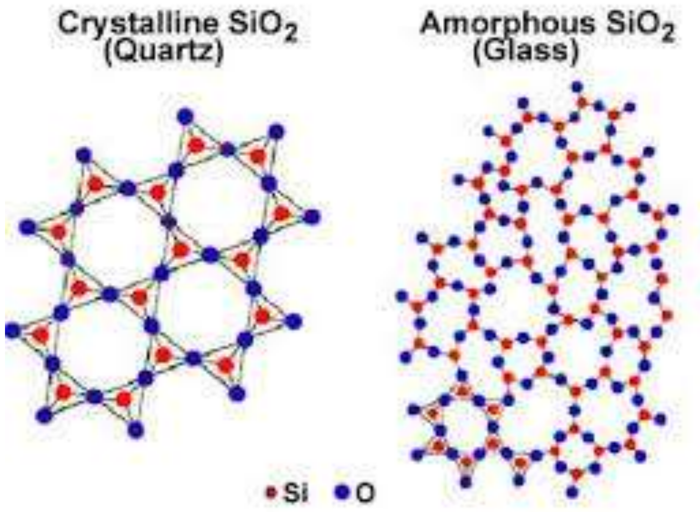
Approximate composition of ordinary glass (Soda lime glass) is *Na2O . CaO . 6SiO2.*

Glass is extensively used in the following ways:

- ✓ A modern **Boeing 707** jet plane contains more than 5000 components of glass.
- ✓ Fibre glass reinforced with plastics can be used in the construction of furniture, lampshades, bathroom fittings, navy boats, aeroplanes, cars, trucks, etc.
- ✓ In the construction of modern homes, walls and ceilings of hollow glass blocks can be made.

Is Glass a liquid or a solid?

- Usually when a liquid is cooled to below its melting point, crystals form and it solidifies.
- If the viscosity rises enough as it is cooled further, **it may never crystallize.**
- The molecules then have a disordered arrangement, but sufficient cohesion to maintain some rigidity.



What is in glass?

- All glasses contain at least 50% silica, which is known as a glass former.

- **Major constituents:**
  - ✓ Silica sand
  - ✓ Soda ash
  - ✓ Lime stone
  - ✓ Dolomite
  - ✓ Lead oxide
  - ✓ Boric acid

- The composition and properties of glasses can be modified greatly by the addition of various other elements. These are known as Intermediates or Modifiers.

Color

- Salts of chromium (green –yellow)
  cobalt (red – blue)
  cadmium (yellow)
  manganese
  nickel (black)
  selenium (red)

General Properties of glass

- ✓ Amorphous Solid
- ✓ No definite melting point
- ✓ Very brittle
- ✓ Softens on heating
- ✓ Can absorb, reflect and transmit light
- ✓ Good electrical insulator
- ✓ Affected by alkalis
- ✓ Not affected by air,water,acid or chemical reagents .
- ✓ Possesses high compressive strength and since it doesn't have any crystalline structure , no slippage between planes can occur
- ✓ Light in weight because it has homogeneous internal structure similar to liquids

Types of Glasses

Soda Lime Glass

- General purpose glass
- Lowest cost
- It is used in the manufacture of glass tubes and other laboratory apparatus, plate glass, window glass, etc

Lead-potash-silica glass

- It is made by using lead oxide
- High refractive index
- Relatively soft surface
- High electrical resistivity
- Radiation protection (higher lead oxide contents typically 65%absorb gamma rays and other forms of harmful radiation
- It is used in the manufacture of artificial gems, electric bulbs, lenses, prisms etc.

Borosilicate Glass

Very resistant to chemical attack

Easy to cut

High luminous transmission

- Uses are touch control panels, LCD, solar cells , chemical glassware.

Lithium Potash Borosilicate Glass

Relatively high operating temperature

Microwave window applications

Low coefficient of thermal expansion

Excellent sealing characteristics

Glass Ceramics

- Glass Ceramics have a high Crystalline component to their microstructure.
- They have a near-zero coefficient of thermal expansion.
- They are strong because of the absence of the porosity found in conventional ceramics.

Examples:

- Cookware
- Heat Exchangers
- Gas Turbine Engines
- Housing for Radar Antennas