Optoelectronics is a main segment of the semiconductor industry. Optoelectronic devices include the light emitting diode (LED), semiconductor laser, and various photodetectors, including the photovoltaic cells. Photodetectors rely on light induced carrier generation. The simplest such device is a photodetector, which is merely a semiconductor device.

## 16.7 COMPOSITE MATERIALS

When two or more materials with very different properties are combined together they form a composite material. The different materials work together to produce a new material, which combines all of the properties of the previously separate materials Within the composite it is still possible to easily tell the different materials apart. They do not tend to blend or dissolve each other. Composite Materials can be either man-made but they may also exist in nature. e.g. Mud Bricks, Car Tyres, Concrete and Fibreglass.

A composite material consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases, with an interface separating them. It has characteristics that are not depicted by any of the components in isolation. Most commonly, composite materials have a bulk phase, which is continuous, called the *matrix*, and one dispersed, non-continuous, phase called the *reinforcement*, which is usually harder and stronger.

The concept of composite material is ancient: to combine different materials to produce a new material with performance unattainable by the individual constituent. An example is adding straw to mud for building stronger mud walls. Some more recent examples, but before engineered materials became prominent, are carbon black in rubber, steel rods in concrete, cement/asphalt mixed with sand, fiberglass in resin etc. In nature, examples abound: a coconut palm leaf, cellulose fibers in a lignin matrix (wood), collagen fibers in an apatite matrix (bone) etc. The essence of the concept of composites is this: the bulk phase accepts the load over a large surface area, and transfers it to the reinforcement, which being stiffer, increases the strength of the composite. The significance here lies in the there are numerous matrix materials and as many fiber types, which can be combined in countless ways to produce just the desired properties.

Most research in engineered composite materials has been done since 1965. Today, given the most efficient design, of say an aerospace structure, a boat or a motor, we can make a composite material that meets or exceeds the performance requirements. Most of the savings are in weight, strength/weight, etc.

**Components of Composite Materials**

*** Bulk phase: matrix materials**

Polymers
Metals
Ceramics

*** Reinforcement: fibers and particulate**

Glass
Carbon
Organic
Boron

Ceramic

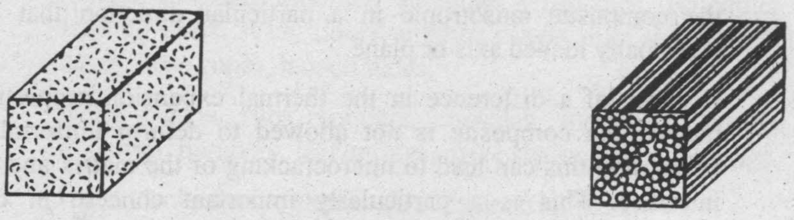
Metallic

*** Interface**

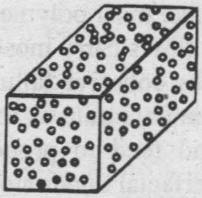
1. Fibers as the reinforcement (Fibrous Composites):

a. Random fiber (short fiber) reinforced composites

b. Continuous fiber (long fiber) reinforced composites)



2. Particles as the reinforcement (Particulate composites)



3. Flat flakes as the reinforcement (Flake composites)

4. Fillers as the reinforcement (Filler composites):

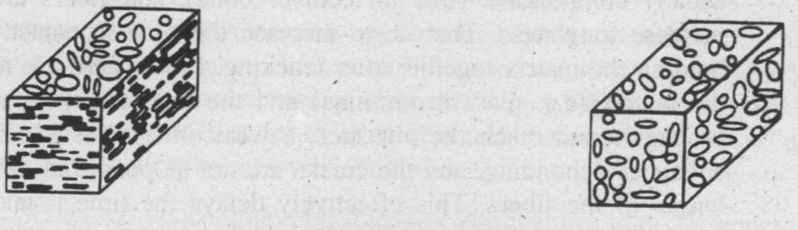


*Fig. 16.5. Classification of composite materials*

## Classification of Composite Materials

The reinforcement system in a composite material strongly determines the strengthening mechanism in a composite. It is thus convenient to classify composites according to the characteristics of the reinforcement, such as length orientation etc. (Fig. 16.5)

## Properties of Composites

We will consider the results of incorporating fibers in a matrix. The matrix, besides holding the fibers together, has the important function of transferring the applied load to the fibers. It is of great importance to be able to predict the properties of a composite, given the component properties and their geometric arrangement.

a) Fiber reinforced composite materials typically exhibit anistrophy. That is, some properties vary depending upon which geometric axis or plane they are measured along.

b) For a composite to be isotropic in a specific, such as Young's modulus, all reinforcing elements, whether fibers or particles have to be randomly oriented. This is easily achieved for discontinuous fibers, since most processing methods tend to impart a certain orientation to the fibers.

c) Continuous fibers in the form of sheets are usually used to deliberately make the composite anisotropic in a particular direction that is known to be principally loaded axis or plane.

d) Because of a difference in the thermal expansion properties of fibers and matrix, the composite is not allowed to deform uniformly under thermal stress, and this can lead to microcracking of the matrix and debonding at the interface. This is a particularly important concern in dental composite materials where thermal stresses are significant.

e) In a ductile matrix, like most polymers and metals, a strong interfacial bond is important, since the fibers carry most of the load in such matrices. Fibers tend to fail first, usually by cohesive failure through the fiber cross-section. This is because the fibers cannot strain as much as the matrix (e.g. carbon in eposy). Cracks are few, and tend to propogate slowly. When the cracks hit the interface, strong interfacial bonds stop them.

f) In a brittle matrix, like ceramics, the matrix carries most of the load, which is usually compressive (like in teeth or bone), and fibers are added only to increase toughness. That is, to increase the time to catastrophic failure by holding the matrix together after cracking. Fibers here are more ductile than the matrix (e.g. glass in alumina) and the matrix fails first. As the cracks propagate and reach the interface, a weak interfacial bond is desired. This enhances debonding, and the cracks are not stopped, but deflected along the length of the fibers. This effectively delays the time it takes the cracks to propagate through the entire matrix, and thus increases toughness.

### Application of Composite Materials

Composite materials have fully established themselves as workable engineering materials and are now relatively common place around the world, particularly for structural purposes. Early military applications of polymer matrix composites during World War II led to large-scale commercial exploitation, especially in the marine industry, during the late 1940s and early 1950s. Today, the aircraft, automobile, leisure, electronic and medical industries are quite dependent on fiber-reinforced plastics, and these composites are routinely designed, manufactured and used. Less exotic composites, namely particulate or mineral filled plastics are also widely used in industry because of the associated cost reduction. Some typical applications of polymer matrix composites are listed in Table 13.1.

**Table 16.1. Some applications of polymer matrix composites. (Adapted from Hull, 1981)**

| Industrial sector | Examples |
|---|---|
| Aerospace | Wings, fuselage, radomes, antennae, tail-planes, helicopter blades, landing gears, seats, floors, interior panels, fuel tanks, rocket motor cases, nose cones, launch tubes. |
| Automobile | Body panels, cabs, spoilers, consoles, instrument panels, lamp-housings, bumpers, leaf springs, drive shafts, gears, bearings. |
| Boats | Hulls, decks masts, engine shrouds, interior panels |
| Chemical | Pipes, tanks, pressure vessels, hoppers, valves, pumps, impellers |
| Domestic | Interior and exterior panels, chairs, tables, baths, shower units, ladders. |
| Electrical | Panels, housings, switchgear, insulators, connectors |
| Leisure | Motor homes, caravans, trailers, golf clubs, racquets, protective helmets, skis, archery bows, surfboards, fishing rods, canoes, pools, diving boards, playground equipment. |

In a similar manner to polymers and ceramics, metals may be reinforced by continuous fibers, discontinuous fibers or particulates. Silicon carbide and alumina are the most frequently employed reinforcements and a wide range of composites have been produced. However, most metal matrix composites are still under development and there are only a few examples of commercial components currently in service (Table 13.2)

Recent interest has concentrated on transport applications and consequently the light metals, particularly aluminum and its alloys, have received the most attention. The Young's modulus of aluminum and its alloys is relatively low for metals and hence there is considerable potential for improvement by reinforcement. However the reader will recall that the forte of metals is their good ductility and toughness and obviously it is desirable that these properties are not degraded in metal matrix composites.

**Table 14.2. Some applications of ceramic and metal matrix composites.**

| Industrial sector | Application | |
|---|---|---|
| | Ceramic matrix | Metal matrix |
| Aerospace | Afterburners, brakes, heat shields, rocket nozzles | Struts, antennae |
| Automobile | Brakes | Piston, crowns |
| Manufacturing | Thermal insulation, cutting tools, wire drawing dies. | |
| Electrical | | Superconductors, contacts, filaments, electrodes |
| Medical | Prostheses, fixation plates | |