28.1 Multilayer Ceramic Capacitors

Multilayer ceramic capacitors (MLCC) are the capacitors most commonly used in electronic circuits (television, radio, telephone, automobile, aeronautics, space, etc.). The main advantages are low cost, small size, a good level of chemical inertness, due to the fact that they are made from chemically very stable oxide ceramics, and hence good stability in time.

Most of the dielectrics in these capacitors are essentially based on barium titanate, which implies a very high dielectric constant and excellent electrical insulating properties. For more than twenty years now, it has been understood that ceramic dielectrics made with grains measuring a hundred or so nanometers, one of the earliest types of nanomaterial, would be able to meet the requirements of the evolving electronics industry.

28.1.1 What Is a Multilayer Ceramic Capacitor?

In the field of electronic or electrotechnical components, a capacitor is a system of two conductors, generally placed close together with opposing faces separated by an insulator, e.g., two parallel metal plates separated by a certain thickness of air, or two aluminium foil sheets stuck on either side of a sheet of paraffin paper. The two conductors are the electrodes of the capacitor, while the insulator is the dielectric.

The capacitance $C$ of the capacitor is proportional to the effective surface area $S$ of the plates, inversely proportional to the thickness $e$ of the dielectric, and proportional to a characteristic quantity associated with the dielectric material called its permittivity $\varepsilon$ (see Fig. 28.1a). The permittivity $\varepsilon$ is often replaced by the product $\varepsilon_0\varepsilon_r$, where $\varepsilon_0$ is characteristic of the physical units and $\varepsilon_r$ is a dimensionless quantity, hence independent of the units, characteristic of the dielectric material and called the relative permittivity, or simply the dielectric constant of the material. Hence,
If the dielectric is a ceramic material, one then has a ceramic capacitor. These materials generally yield high values of $\varepsilon$. To increase the capacitance without making the surface area too big, efforts have been made to reduce the dielectric thickness, moving from a disk technology to a multilayer technology. This leads to multilayer ceramic capacitors (MLCC), comprising $n$ layers of thickness $e$. This is equivalent to $n$ identical capacitors of thickness $e$ mounted in parallel (see Fig. 28.1b):

$$C = n\frac{\varepsilon S}{e}.$$  \hspace{1cm} (28.2)

In practice the dielectric must fulfill at least two functions: it must ‘store’ electrical charge, an aptitude characterised by its permittivity $\varepsilon$, but it must also be a good electrical insulator, to ensure that the charges cannot transfer from one electrode to the other, an aptitude characterised by its resistivity $\rho$.

Various technologies are used to make MLCCs, but the process always ends with a stage in which the ceramic and metal layers are cosintered. This restricts the choice of material, but it also imposes an economic constraint. In particular, since the dielectrics are usually oxides, cosintering must be carried out in air. This requires the use of precious metals, usually silver–palladium alloys, to make the internal electrodes.

**Cosintering Ceramic and Metal Layers**

Before explaining what cosintering involves, it will be useful to recall the basic idea of sintering. The usual definition is: consolidation of a granular agglomerate under the action of heat, with or without melting of one or more components. Put in a more accessible way, sintering is an operation that consists in transforming a workpiece (referred to as the green body in ceramics) made by moulding a dried slurry, itself comprising an assembly of grains that are not permanently fused together (with or