Are there any dia-electric materials?

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Trend lines predict [1] that capacitors will become the leading energy storage technology [2, 3] within the next decade. In addition they are potentially an enabling technology for a more robust and resilient power grid [4] and more efficient and safer nuclear power plants [5]. Capacitors are made of two layers of conducting materials. Between the conductors is a vacuum gap [3], or a material with low conductivity such as Teflon or air. Gap materials with special electric properties are used to fabricate capacitors for specific applications. For instance Teflon capacitors have a large dielectric strength and therefore withstand large voltages. Calcium copper titanate capacitors have a large dielectric constant and therefore can store a comparatively large amount of energy at small voltages. Finding materials with unusual electric properties helps to design capacitors with special properties.

Figure 1 Sketch of the field lines of a positive charge (a), a positive charge and a dielectric sphere (b), and a positive charge and a dia-electric sphere (c). The arrows indicate the forces.
Dia-electricity is such an unusual property. In contrast to dielectric materials, the force between dia-electric material and a charge is repulsive. The repulsive force is like the repulsive force between magnets and diamagnetic materials. A sphere of diamagnetic material creates a magnetic field which is opposed to the external field and diverts the field lines away from the sphere. Similarly a sphere of dia-electric material is expected to create an electric field which diverts the electric field lines away from the sphere (see Fig. 1c), whereas a dielectric material does the opposite (see Fig. 1b). All materials show a diamagnetic response, however many materials have other stronger responses in addition, such as ferromagnetism. Only those materials where the diamagnetic response is larger than all other responses combined are called diamagnetic. Many common substances are diamagnetic, including water, wood, most organic compounds such as petroleum and some plastics, and many metals including copper, silver, and gold. Many common materials are known to be attracted by a charge, but no material has been found which are repelled by a charge, i.e. where the dia-electric response exceeds all other interactions with a charge.

In the following we show that aluminum spheres in air are repelled from a charge and argue that materials with a small work function have a large dia-electric response. Figure 2 shows pictures of the experimental setup. A 10 g sphere of crumpled aluminum foil with a radius of 1cm is suspended on a thin yarn in air (see Fig. 2a). Below the sphere is a high voltage electrode with a 100 micron tip radius. The gap between the sphere and the electrode tip is 2 mm. 30 cm above the sphere is a grounded conducting plate with radius 10cm. When a voltage of 25kV is applied to the high voltage electrode the sphere is repelled (see Fig. 2b). When the high voltage electrode is discharged, the sphere returns to its original position.

Figure 1. An aluminum sphere shows a dia-electric response. Initially the sphere is suspended on a thread above a high-voltage electrode (a). When the electrode is charged the sphere is repelled (b).
The aluminum sphere shows a dia-electric response, because it is repelled from the electrode. We assume that two forces act on the sphere: (a) an attractive force due to the induced electric dipole moment and (b) a repulsive force because the field emission current between the electrode and the sphere deposits a positive charge on the sphere. Apparently the net force is repulsive and therefore the aluminum sphere is dia-electric.

Supposedly the charging of the sphere depends on the magnitude of the field emission current. If the field emission current is suppressed, for example with an insulating coating, the aluminum sphere would most likely be attracted by the charge, and the sphere would be considered dielectric.

The magnitude of the field emission current depends on the work function of the material. Therefore we would expect materials with a small work function to have a large dia-electric response. Materials with a small work function include alkali metals and aluminum [6].