Bulk Semiconductor Levitation by use of Electrical Current and the Earth's Magnetic Field

In this paper I present a method for the levitation of a bulk semiconductor by use of the Earth's magnetic field acting on an electrical current through the semiconductor. The theory is simplified to the case of a large semiconducting sample with a strong electrical current and specific examples are discussed for different elemental semiconductors.

3D Bulk Resistivity

The 3D bulk resistivity, ρ, of a semiconductor is a measured and accepted standard of the resistivity for a given type of semiconductor in the bulk 3D form. It is usually quoted for a given semiconductor in units of Ω·m (resistance·length). For a given bulk sample of a semiconductor with a given set of dimensions, the resistance of the sample may be calculated from the 3D bulk resistivity. This is explained in a simple equation relating the resistivity to the resistance, R, along the semiconductor sample (when considering a specific direction of current), the cross-sectional area , A, of the semiconductor (in the plane that is normal to the direction of the current) and the length of the semiconductor sample, L, as follows;

$$R = \rho \frac{L}{A}$$

The Earth's Magnetic Field

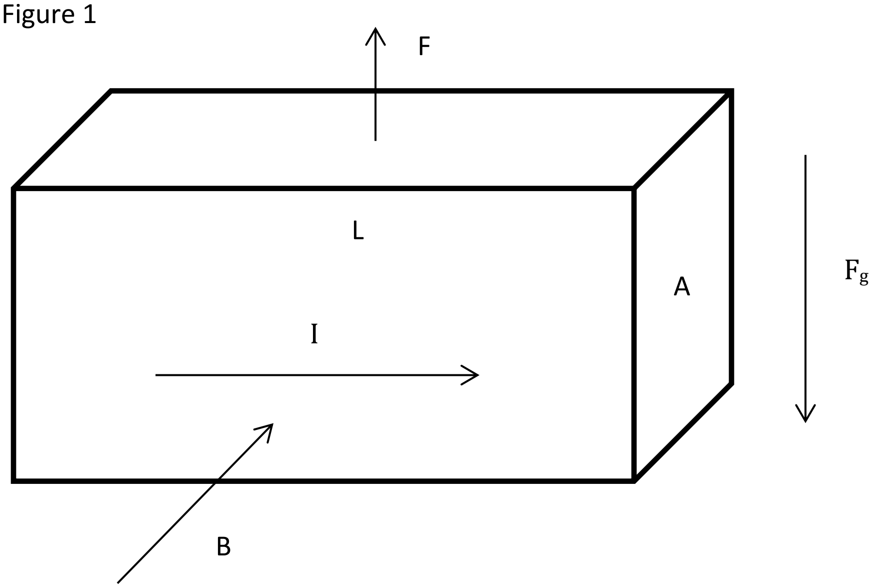
The strength of the magnetic field of the Earth is a variable quantity which will change in direction relative to the Earth's surface. At the north and south poles the magnetic field is normal to the Earth's surface, but at the equator the magnetic field is parallel to the surface and runs from north to south. In this paper we only wish to consider the component of the Earth's magnetic field which is in a direction near parallel to the surface of the Earth and normal to the direction of the Earth's gravitational force. This is because we wish to use the magnetic field to "levitate" a semiconductor which would be to force its motion in the direction that counters the force of gravity. If we consider the Earth's magnetic field in the direction parallel to the Earth's surface then we will be talking about a magnetic field strength that is roughly on the order of 0.5 Gauss (or 5×10^{-5} Tesla, where 1 Tesla = 1 kg/A·s^2). From here on out we will strictly refer to this component of the Earth's magnetic field as B.

In the above paragraph I have considered the component of the Earth's magnetic field that is "near" parallel to the surface of the Earth. To be explicitly clear, I consider all components of the Earth's magnetic field which may be used for the purpose of propulsion of a bulk semiconductor in an upward direction (against gravity) and in any direction in the plane normal to upward. However, to simplify the writing of this theory I only explain the effect for the upward direction.

Semiconductor Levitation

If we wish to consider a specific sample of a semiconductor (with a known resistivity, ρ) with specific dimensions then the semiconductor will have a known drift velocity of charge carriers (electrons and holes) that is a function of the applied voltage and other variables. This drift velocity of the charge carriers will have a threshold value at a specific voltage for a given semiconductor, beyond which if one was to increase the applied voltage then the number of charge carriers must increase (to account for the increase in current). We will analyse the applied force on the semiconductor sample due to the Earth's magnetic field and in doing so we will refer to the drift velocity of the charge carriers, v, and we assume it to be the constant threshold value because we only consider the case of high voltage/current. So we will also consider that the number of charge carriers, N, is variable and that it alone will determine any variation in the current.

Figure 1



In Figure 1 we illustrate our bulk semiconductor sample with length, L, and cross-sectional area, A, and we apply a voltage such that the sample carries current I along the length of the sample. The sample is placed such that the Earth's magnetic field, B, is normal to the current and normal to the force of gravity, F_g.

What we wish to calculate is the force on the semiconductor sample due to the effect that the Earth's magnetic field has on the charge carriers in the sample, F. If the sample was metal there would be a different effect because the magnetic field does not penetrate the metal the same way, but with a semiconducting medium the magnetic field will penetrate right through the sample uniformly and this will have an effect on all of the charge carriers that are responsible for the current. Each charge carrier is assumed to have the charge of one positive elementary electronic charge, $e=1.6\times10^{-19}$C, rather than analysing this problem in the context of electrons and holes with opposite motion and charge. [It is worth noting at this point that the charge carriers will not react to the magnetic field by moving "within" the sample, but rather that the whole of the sample reacts to the action of the magnetic field on the charge carriers. The reason for this involves the interpretation of quantum mechanics and solid state physics.] The effect that the Earth's magnetic field has on the whole of the bulk sample is determined by a sum of the effect that the field has on all of the charge carriers. This effect is the exertion of a force on the sample, F, that is calculated with the Lorentz Force Law,

$$F = Q\boldsymbol{v} \times \boldsymbol{B}$$

Where $\boldsymbol{v}$ and $\boldsymbol{B}$ are orthogonal vectors so that $\boldsymbol{v} \times \boldsymbol{B} = vB$. The variable Q is the total charge so we may equate this to $Q = Ne$. Substituting these into our equation we get,

$$F = NevB$$

Now we need to deal with one variable in our calculation, the total number of charge carriers, N. Ideally we would be able to substitute this for the current, I, so we need to make a simple calculation which assumes a much longer dimension of sample with a similar current through it. This imaginary sample will carry the same current, I, over a length of the sample, x, which is equal to the length that the drift velocity will travel over time t, $x=vt$. Current is a measure of charge per time, $I=Q_i/t$, where the imaginary sample has a total charge of $Q_i=N_ie$ and N_i is the total number of charge carriers in the imaginary sample. So for the imaginary sample carrying current I we can calculate the number of charge carriers simply as $N_i = Q_i/e = It/e = Ix/ve$. This means that a similar semiconducting sample, like our sample with length L, will have a total number of charge carriers as

$$N = \frac{N_i}{x}L = \frac{Ix}{xve}L = \frac{IL}{ve}$$

This may now be used to simplify our equation for the force on the semiconducting sample,

$$F = \frac{IL}{ve}evB = ILB$$

This is an important conclusion that we may consider to be fundamental to a semiconducting sample that is placed in a magnetic field; when there is a current applied through the sample that is orthogonal to the field (which we assume to be in the direction normal to the force of gravity) then there is a force exerted on the sample which is orthogonal to both of the current and field (which for this example is an upward force which opposes gravity) and this force is directly proportional to the current, the length of the sample and the field strength.

So for our calculation if we may assume that the Earth's magnetic field is in the direction from north to south, then the current applied to the sample must flow from east to west. To analyse things further, the current, I, may now be substituted for the resistance, R, and voltage, V, as

$$F = \frac{V}{R}LB = \frac{VA}{\rho L}LB = \frac{VAB}{\rho}$$

This puts our equation in terms of the 3D bulk resistivity, ρ, and the applied voltage, V.

So now let's consider that the sample is to be "levitated", meaning that we must have equality between the Lorentz force, F, and the force due to gravity, $F_g = mg = \alpha ALg$, where α is the density of the sample. Equating the forces we get,

$$F = F_g$$

$$\frac{VAB}{\rho} = \alpha ALg$$

$$V = \frac{\alpha\rho Lg}{B}$$

So in order to levitate a semiconducting sample one must apply a voltage which is proportional to the density, the resistivity and the length. Another way of looking at this is to use current rather than voltage, which would lead to the following result for required levitation current,

$$I = \frac{\alpha Ag}{B}$$

So in order to levitate a semiconducting sample one must apply a current along the length of the sample which is proportional to the density and the cross-sectional area.

So let's look at a couple of examples of elemental semiconducting samples. If we use a sample of doped Si with resistivity of 2.3Ω·m and a density of 2.3×10^3kg/m^3 which gives a levitation voltage of (assuming that the Earth's magnetic field $B \approx 5.3\times10^{-5}$T)

$$V \approx \frac{10^9 Volts}{meter} L$$

So for a bulk Si sample of a given length we would require a voltage across the sample of 10^9Volts for every meter of length of the sample in order to levitate the sample. If you increase the cross-sectional area then this will lower resistance which would increase the current at constant voltage.

We can also calculate the levitation current as

$$I \approx \frac{4\times10^8 Amperes}{square\ meter} A$$

So for a bulk Si sample of a given cross-sectional area we would require a 4×10^8Ampere current through the sample for every square meter of cross-sectional area in order to levitate the sample. If you increase the length then the resistance increases and you require a greater voltage to keep the current constant.

If we do the same calculations for a sample of doped Ge with resistivity 0.1Ω·m and a bulk density of 5.3×10^3kg/m^3 we would calculate the levitation current and voltage as

$$V \approx \frac{10^8 Volts}{meter} L$$

$$I \approx \frac{10^9 Amperes}{square\ meter} A$$

If we do the same calculations for a sample of doped graphite with resistivity $10^{-4}\Omega\cdot m$ and a bulk density of $2\times10^3 kg/m^3$ we would calculate the levitation current and voltage as

$$V \approx \frac{4 \times 10^4 Volts}{meter} L$$

$$I \approx \frac{4 \times 10^8 Amperes}{square\ meter} A$$

Now we have a much more practically applicable example with doped graphite. Practical application requires a much lower resistivity like graphite has, and this leads to a much lower voltage required in order to levitate a $1m^3$ sample (which has a mass of ≈2 tonnes). If we lower the dimensions so that the sample is a large sheet with length 1m, width 0.1m and height 0.01m (which has a mass of ≈2kg) and we apply the current lengthwise then we would calculate the levitation current and voltage as

$$V \approx 40kV$$

$$I \approx 400kA$$

This requires an electrical power (P=IV) of 16 GW in order to levitate the sample.

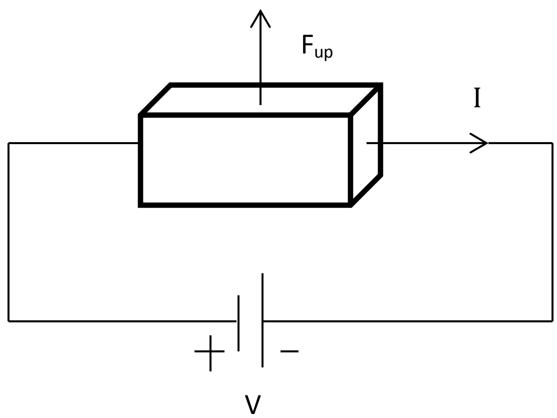
To discuss practicality in this analysis will lead us to require low power for levitation and lower power requires using a semiconducting sample with the lowest possible resistivity and the lowest possible density. But one must not be mis-lead by the intuition that a smaller sample will be lighter and would reduce the load, so that one would choose to use the least massive sample possible for a given task. It's actually the opposite, the larger/heavier the better. Strangely enough we must think Texas-style; bigger is better. From the above calculation we can see that the small sample of graphite (which has a resistance of 0.1Ω) can be levitated by simply applying a 40kV voltage difference across the sample (which would cause 400kA of current through the sample). If you increase the size of the sample by increasing the cross-sectional area then you lower the resistance and a greater current will flow at the same voltage. The large sample of graphite (which has a resistance of 0.0001Ω) can be levitated by applying a 40kV voltage difference across the sample (which would cause 400MA of current through the sample).

Considering the above analysis we see that the same voltage will levitate a small sample of graphite and a larger sample of graphite that has the same length along the direction of the current. Not only this, but it is implied by the above analysis that if we were to double the voltage then we would double the Lorentz force;

$$F = ILB = \frac{VLB}{R}$$

The force applied upward by the magnetic field's action on the sample, *F*, is directly proportional to the voltage, *V*. So if we start with a very large sample rather than a very small sample, then doubling the force only requires doubling the voltage. Let's say we are using the $1m^3$ sample of graphite which was calculated to have a levitation voltage of 40kV, and a weight of 2 metric tonnes. By simply doubling the voltage to 80kV we have doubled the current (to 800MA) and produced an upward force of 2 tonnes. If we were using the smaller graphite sample (1m × 0.1m × 0.01m) then the levitation voltage is the same, 40kV, and doubling the voltage to 80kV would double the current (to 800kA) but this would only produce an upward force of 2kG. The upward force that we produce with voltage is a function of the weight of the sample (as long as we don't vary the voltage and sample length). This doesn't say anything about current as we assume our circuit is capable of handling the current load.

Figure 2



So now we need to calculate this additional upward force, so we refer to Figure 2. This analysis can be done with an equation that relates the upward force, F_{up}, to the Lorentz force, *F*, and the weight of the sample, F_g;

$$F_{up} = F + F_g$$

$$F_{up} = \frac{V}{R}LB - mg$$

The upward force produced will be directly proportional to the voltage , *V*, while at a constant resistance, *R*. The voltage can in turn be expressed as a sum of the levitation voltage, V_L, and the additional voltage increased, V_A. With this substitution ($V = V_L+V_A$) we get,

$$F_{up} = \frac{V_L}{R}LB + \frac{V_A}{R}LB - mg$$

One might note that the weight, *mg*, is equal to the first term on the right side,

$$mg = \frac{V_L}{R}LB$$

So we now arrive at a final expression for the upward force,

$$F_{up} = \frac{V_A}{R} LB$$

This expression shows that the upward force is directly proportional to the additional voltage but inversely proportional to the resistance. Due to the fact that the additional force is inversely proportional to the resistance, there is a much greater upward force for a sample with a larger cross-sectional area, because a larger area produces a smaller resistance. Of course, due to the lower resistance there is a greater current load which must be accommodated. This requires the use of heavy-duty wiring for the remainder of the circuit. If we look at Figure 2, we would say that the remainder of the circuit other than the sample must use heavy-duty wiring. Another way of saying this is to demand that the remainder of the circuit other than the sample must have a resistance which is much less than the resistance of the sample.