Ultra-Conductive Magnesium

Fran De Aquino
Professor Emeritus of Physics, Maranhao State University, UEMA.
Titular Researcher (R) of National Institute for Space Research, INPE

www.frandeaquino.org
deaquino@elointernet.com.br

The improvement of the electrical conductivity of usual metals is limited by the *purity* of the metal and the ability to grow single crystal structures. Also, it was observed that the AC conductivity of the metal increases when the frequency of the electrical current applied on the conductor increases. Here, we show that the pure *Magnesium* metal can exhibit an *ultrahigh* electrical conductivity when it is subjected to 360K temperature, and an electrical current with frequency of the order of 1GHz.

Key words: Ultra-conductivity, Pure Magnesium, GHz.

INTRODUCTION

There is a search for conductors with *ultrahigh* electrical conductivity because they can lead to higher efficiency and less energy consumption in a wide range of applications.

By embedding graphene in metals (Cu, Al, and Ag), it was recently obtained a maximum electrical conductivity three orders of magnitude higher than the highest on record (more than 3,000 times higher than that of Cu, i.e., $\cong 10^{11}\,S/m$) is obtained in such embedded graphene [1]. The improvement of the electrical conductivity of usual conductors is basically limited by the purity of the metal. However, experimental studies show that the AC conductivity of some metals *increase* when the *frequency* of the electrical current applied on the metal *increases* [2]. It is here shown that the pure *Magnesium* metal can exhibit an *ultrahigh* electrical conductivity when subjected to 360K (87°C) temperature, and an electrical current with frequency of the order of 1GHz. Why prioritize the *Magnesium*? First because, is relatively easy to obtain Magnesium highly pure (99.999%). Second because, *ultra-conductive Magnesium* can be fundamental for the building of several novel devices, such as *Gravitational Motors*, *Gravitational Thruster of Fluids*, production of *Microgravity environments*, and a *Cooling and Heating Gravitational System* [3].

THEORY

The AC electric conductivity is the electric conductivity originated from a potential dependent of time (For example, when AC current is *applied* on a conductor). The DC electric conductivity does not depend on the time; this conductivity is the well-known electrical conductivity that arises when a DC source is applied on the conductor. Thus, total electrical conductivity of a conductor is given by [2].

$$\sigma_{total} = \sigma_0 + \sigma_{AC} \qquad (1)$$

where σ_0 is the part of the total conductivity which value is frequency-*independent* and temperature-dependent, it which arises from the drift mobility of electric charge carriers. So σ_0 is actually DC electrical conductivity; σ_{AC} is the part of the total conductivity which value is the frequency - and temperature – dependent, and is correlated to dielectric relaxation produced by localized electric charge carriers; usually σ_{AC} is expressed by

$$\sigma_{AC} = \sigma^*\left(\frac{\omega}{\omega_0}\right)^s = k\sigma_{DC}\left(\frac{\omega}{\omega_0}\right)^s = \sigma_{DC}\left(\frac{\omega^s}{\omega_c^s}\right) \qquad (2)$$

where σ^* and s are composition – and temperature-dependent parameters; $0 < s < 1$ [2]. $w = 2\pi f$; $\omega_c = 2\pi f_c$, where f_c is a critical value to be determined.

Substitution of Eq. (2) into Eq. (1) gives

$$\sigma_{total} = \sigma_{DC}\left(1 + \frac{f^s}{f_c^s}\right) \qquad (3)$$

Therefore, the total electrical conductivity of a conductor is directly proportional to the *frequency* f *of the electrical current applied* on the conductor [4].

In the particular case of $f^s / f_c^s >> 1$ Eq. (3) reduces to

$$\sigma_{total} \cong \left(\frac{f}{f_c}\right)^s \sigma_{DC} \qquad (4)$$

Experimental studies have revealed that

below 10 GHz the frequency as well as the temperature effect is negligible [2] (*this point to a value of the order of* 10 GHz *for critical frequency* f_c *at room temperature*). At higher temperature, however, there is an increasing contribution resulting from ion mobility and crystal imperfection mobility. Also, at a higher temperature, *conductivity effect becomes dominant*. As the temperature increases, AC electrical conductivity increase due to increase in the drift mobility of thermally activated electrons [5], and *reaches a maximum value at a critical temperature* $T_C \cong 360K$ (87°C), then decreases with temperature [2]. On the other hand, since Eq. (2) tells us that

$$\omega_c^s = \frac{\omega_0^s}{k} = \frac{(2\pi f_0)^s}{k} = (2\pi f_c)^s \qquad (5)$$

where $k = \sigma^* / \sigma_{DC}$ (See Eq. 2). Then, Eq. (5) gives

$$f_c^s = \frac{f_0^s}{k} = f_0^s \left(\frac{\sigma_{DC}}{\sigma^*} \right) \qquad (6)$$

or

$$f_c = f_0 \left(\frac{\sigma_{DC}}{\sigma^*} \right)^{\frac{1}{s}} \qquad (7)$$

It is well-known that σ^* is temperature – dependent, and that it *increases much more* with the increase of the *temperature* than σ_{DC} [2]. Then, assuming that

$$\sigma_{DC} = \sigma\, F(T) \approx \sigma \qquad (F(T) \approx 1) \qquad (8)$$

$$\sigma^* = \sigma\, F^*(T) \cong \sigma\, f_0^{s\left(\frac{T}{T_C}\right)} \qquad \left(F^*(T) \cong f_0^{s\left(\frac{T}{T_C}\right)} \right) \qquad (9)$$

where $F(T)$ and $F^*(T)$ are, respectively, temperature-functions of σ_{DC} and σ^*, and $T_C \cong$ *360K* (87°C) is the *critical temperature* previously mentioned.

Substitution of Eq. (8) and Eq. (9) into Eq. (7) yields

$$f_c^s = f_0^s \left(\frac{f_0^s}{f_0^s} \frac{\sigma}{\sigma\, f_0^{s\left(\frac{T}{T_C}\right)}} \right) = \left(\frac{f_0^s}{f_0^{s\left(\frac{T}{T_C}\right)}} \right) = \left(f_0^{1-\frac{T}{T_C}} \right)^s \qquad (10)$$

whence

$$f_c = f_0^{\left(1-\frac{T}{T_C}\right)} \qquad T \le T_C \qquad (11)$$

As we have seen, $f_c \cong 10GHz$ at room temperature $(T = 25°C)$. Then assuming that $T_C \cong 87°C$, we obtain from Eq. (11):

$$f_0 \cong 10^{14}\,Hz \qquad (12)$$

Therefore, according to Eq. (11), we have

For $T = 0°C \Rightarrow f_C = 10^{14}\,Hz$;

For $T = \frac{1}{4}T_c \cong 21.7°C \Rightarrow f_C = 31GHz$

For $T = \frac{1}{3}T_c \cong 29°C \Rightarrow f_C = 2.1GHz$

For $T = \frac{1}{2}T_c \cong 43.5°C \Rightarrow f_C = 10MHz$

For $T = T_c \cong 87°C \Rightarrow f_C = 1Hz$

Therefore, based on Eq. (11), we can conclude that f_c strongly *decreases with the increasing of the temperature* T. At $T = T_C$ the value of the critical frequency f_c should reach the maximum decrease, reducing down to a few Hz only. Under these conditions, for $f \approx 1GHz$, the factor f / f_c (See Eq. 4) should reach a value of the order of 10^9. Increasing therefore, the total electrical conductivity of the Magnesium for a value of the order of $10^{16}\,S/m$, since the DC electrical conductivity of Mg is about $2.2 \times 10^7\,S/m$. Note that the ultra-conductivity in this case is about 10^5 times higher than the record of $\cong 10^{11}\,S/m$, which it was obtained in the case of embedded graphene, mentioned in the introduction of this paper.

When Magnesium is in its metal form it will burn very easily in air. However, in order to start the reaction (the burning) the Magnesium metal needs a source of energy. The flame provides a source of heat so that the Magnesium metal atoms can overcome their activation energy. The ignition temperature of Magnesium is approximately 744 K (471 °C).

Glass ampoule (Magnesium in this ampoule with argon will remain shiny forever.)

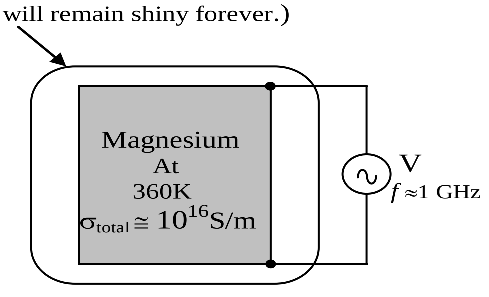


Fig.1 – *Ultra-conductive Magnesium* - Magnesium metal 99.999% pure should exhibits an electrical conductivity of the order of 10^{16} S/m when subjected to 360K temperature, and an electrical current with frequency of the order of 1GHz.

CONCLUSION

Only experimental studies can determine with precision the value of f_c at around 360K. Thus, in conclusion, we suggest that experiments be carried out in order to verify the theoretical results here obtained.

References

[1] Cao, M., et al., (2019) *Ultrahigh Electrical Conductivity of Graphene Embedded in Metals.* Advanced Functional Materials, DOI: 10.102/adfm201806792.

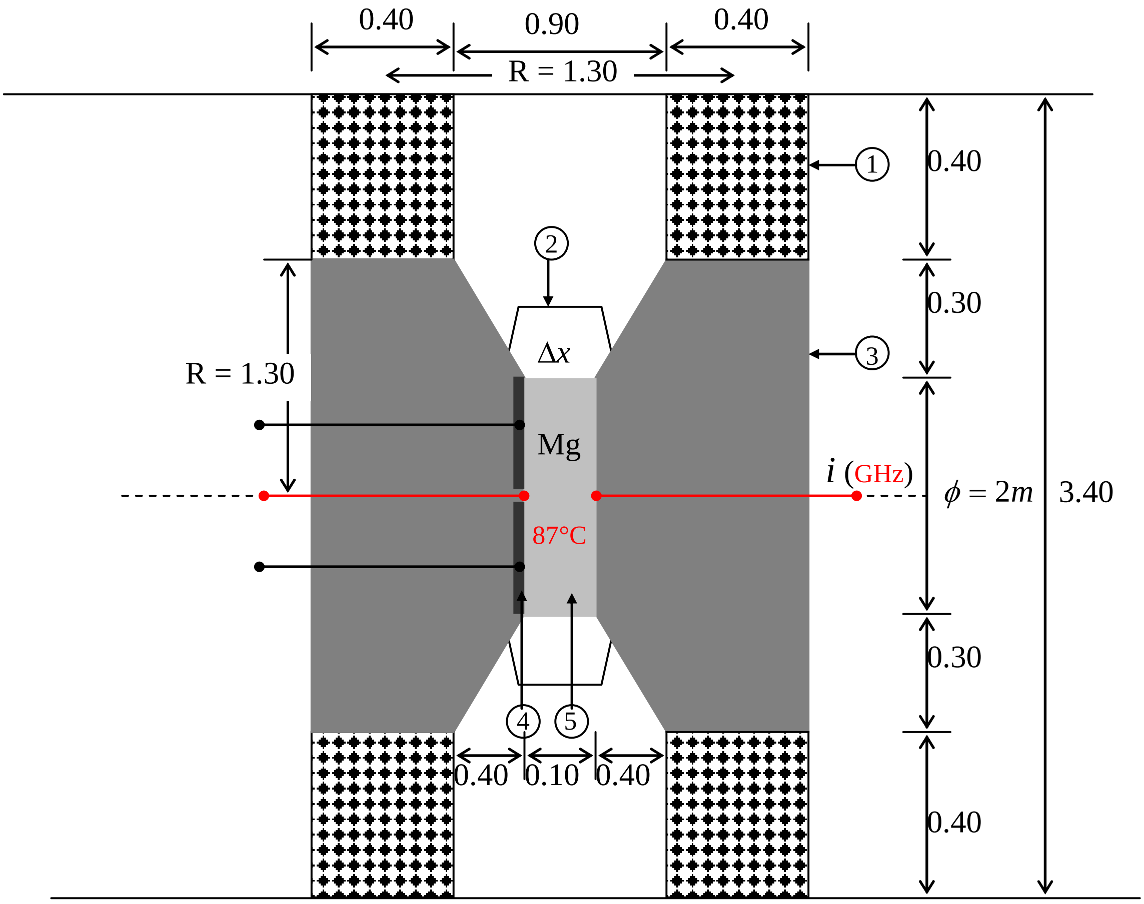
[2] Kurien, S., et al., (2004) Structural and Electrical Properties of Nano-sized Magnesium aluminate. Indian Journal of Pure & Applied Physics, Vol. 42, pp.926-933.

[3] De Aquino, F. (2021) Deceasing of Gravitational Mass of the Magnesium subjected to an Alternating Magnetic Field of Extremely Low Frequency.
Available at:
https://hal.archives-ouvertes.fr/hal-03120208

[4] Smit . J., & Wijn H. P. (1959) Ferrites, Clever-Hume Press, Chapt. XII, London.

[5] El Hiti, M.A. (1994) *J Mag Mater*, pp. 136-138.

APPENDIX: The Reactor for Gravitational Spacecraft.



1- Helmholtz Coil (N turns; I ELF , 0.1Hz)
2- Dome; Argon inside.
3- Iron Core
4- Heater
5- 99.999% Pure Magnesium Disk

* $V_{Mg} = \frac{\pi}{4}\phi^2\Delta x = \frac{\pi}{4}(2)^2(0.10) = 0.314m^3$; $m_{Mg} = \rho_{Mg}V_{Mg} = 1738\times 0.314 = 546.0kg$

* $B = \left(\frac{4}{5}\right)^{2^{\frac{3}{2}}}\frac{\mu_r\mu_0 NI}{R}$; p/ $N = 500turns$; $\mu_r = 1000$ (iron); $R = 1.30m$, we have $B = 3.4\ T$

* Since

$$\chi = \frac{m_g}{m_{i0}} = \left\{1-2\left[\sqrt{1+\left(\frac{\sigma}{4\pi\ f\mu_0\rho^2c^2}\right)B_{rms}^4}-1\right]\right\}$$

Then, for $\sigma \cong 10^{16}\,s/m$, $f = 0.1Hz$, $\rho = 1738kg/m^3$ (Magnesium) and $B_{rms} = 3.4\ T$, equation above gives

$$\chi = \frac{m_g}{m_{i0}} = -1.05$$