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ISSN 0543-5846
METABK 60(1-2) 79-81 (2021)
UDC – UDK 669.3/621-426:62.001.57:537.311.3:511.1/ 539.1:546.21/539.1:111

COPPER WIRE, MODEL AND EQUATION OF ELECTRICAL RESISTANCE

Received – Primljeno: 2020-07-27
Accepted – Prihvaćeno: 2020-10-25
Original Scientific Paper – Izvorni znanstveni rad

Electrical resistance is modeled as conversion of electricity to heat with scattering of axial flux of EE quanta to heat with copper and oxygen electrons. In the derived resistance equation, parameters related to wire substructure, current density and wire temperature are considered. Wire interatoms EE travelling paths are proposed, as well. With 0,00037 wt. % O in copper wire, ASTM quoted resistance is calculated. In absence of electric current, R_c=0, then, copper atoms, J* and oxygen atoms affect the resistance by axial current, rsp quanta flux.

Key words: copper wire, model, electrical resistance, number of atoms, oxygen atoms

INTRODUCTION

Copper wire is a stack of copper atoms with cube crystal lattice atoms sphere and cube atom lattice forms the axial paths of EE current. EE quanta are scattered by vibrating Cu atoms and interstitial oxygen atoms.

Accurate analysis of ASTM data [1] proves that resistance is not related to copper crystal lattice linear and point defects, mobile dislocation [2] and lattice vacancies [3] determining the wire mechanical properties. By decrease of wire thickness from d_1 to d_2, resistance and current density A_{Sa} (number of A/wire cross section area m^2, EE quanta flux density EE_q and R increase as ratio of squares of greater versus lower wire diameter.

By resistance, part of axial EE quanta flux is converted to heat-light radiation with Compton scattering of EE quanta and wire electrons.

Ohm law $W = A \cdot V$ (with W - power, A-electric current, V- voltage), for example: $6W = 3A \cdot 2V = 2A \cdot 3V$ proves that the electrical tension (voltage) is the power available for use at by time:

$$t = {}^{l}\!/_{c} \tag{1}$$

at distance l from the power source.

Data [1] indicate that by listed wires, the resistance is deduced as R_x = 21,954 $10^3/d_x^{\ 2}$ Ω/m [5] with d_x in mm. By decrease of wire thickness, R and A_{Sa} increase equally. Then, by A_{Sa} and $EE_q = 0$, R = 0, as well. Then, resistance is the interaction of wire electrons and EE flux of EE quanta.

The lower resistance of Cu, Ag and with 18,1 electrons in 2 outer shells may be due to larger EE quanta travel paths.

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COPPER ATOM LATTICE SPACE SIZE AND VOLUME EXPANSION

At solidification, free copper atoms bind to crystal as cube lattice atom spaces bound with 6 neighbors with 6 Fermi-valence electrons. By solidification, copper atoms volume shrinks by

$$\Delta V_s = \left(1/y_m^3 - 1/y_s^3\right) \tag{2}$$

$$\Delta V_s) \approx 1{,}52 \cdot 10^{-2}\ \mathrm{cm}^3/\mathrm{cm}^3$$

with y_m= 8,03 and y_s= 8,96 g/cm³ - densities of molten and of solid copper at 1 357,7 and 295 K [4]. Copper atoms space edge is

$$e_{Cu} = \left[\frac{\left(m_{Cu}/\rho_{Cua}\right)}{A^*}\right]^{1/3} \tag{3}$$

$$e_{Cu} = 0{,}2275\, nm$$

with m_{Cu} = 63,546 relative copper atomic weight. The number atoms by 1m of wire, is $l_w/e_{Cu} = 4{,}3956 \cdot 10^9$ and constant, the number of Cu atoms by wire volume 1 m³ is $n_{CuV} = \frac{V_w}{e_{Cu}^3}$.

The FE vibration plane is the plane of equal attraction force of neighbor atom cores.

The EE current is gradually reduced by resistance. In [1], the lowest $R_s = 0{,}1608 \cdot 10^{-3}$ Ω/m [1] by is quoted d_w = 11.684 mm wire. By copper expansion constant k_{ex}= 16,5 10^{-6} m at 295 K [4], the wire atoms expansion amplitude at 298 K is

$$\lambda_e = \frac{\left(\frac{298}{293}\right)\cdot k_{ex}}{n_{Cur}} \tag{4}$$

$$\lambda_e = \frac{1,0101\cdot 16,5\cdot 10^{-6}}{4,3956\cdot 10^{9}}$$

$$\lambda_e = 3,8261\cdot 10^{-15}\ \mathrm{m}$$

By d_w = 11,684 mm and current n_A=1, the number of quanta per atom expansions is

$$n_{hex} = \frac{1,5092\cdot 10^{33}}{9,1014\cdot 10^{24}} \tag{5}$$

$$n_{hex} = 1,6582\cdot 10^{10}$$

with 9,1014 10^{24} - number of Cu atoms/m of d_w = 11,684 mm wire.

RESISTANCE EQUATION

At constant wire temperature, the conductivity, and resistance of copper wire depend strongly of the content of oxygen c_O. The content $c_O = 0,0001$ wt. %, is quoted for the highest OFHC wire [5] conductivity. Oxygen atoms are captured in interstitial crystal lattice points at copper solidification. The atoms expansion vibration amplitude is by about 6 magnitudes lower than the edge of atom cube space, then, is reasonable to assume that interstitial spaces are bordered with nominal copper ions. Considering the experimental and covalent copper atom diameter of ≈ 0.254 nm, the copper ion ionization energies 745 and 1 957 kJ/mol [4] and the field force proportional to $1/r^2$, the spacing of Cu ions is $d_{Cu+} \approx$ 14,02 nm. It is assumed that such lattices place are nests of oxygen covalent atoms with size $d_O = 0,132 \pm 0,004$ *nm*. [5].

In the proposed model, resistance is treated sum of 2 fluxes: wire radiance flux and flux of EEq converted to heat with Compton scattering of EEq to heat on wire atom electrons with radiant energy.

$$J_w^* = k_{SB}\cdot S_s\cdot J\cdot T^4 \tag{6}$$

with k_{SB}-Stefan-Boltzmann constant, S_S- surface area/wire and T-temperature K. According to Ohm equation $W = V \cdot A$ and by V = 1, 1W = 1A and by d_m = 11,684 mm and current 1 A, the electrical energy $1W = 1\mathrm{J}\ s^{-1} = 1\mathrm{A}\ s^{-1}$. Then, by current 1 A, the number of EE quanta is $1/h = 1,5092\cdot 10^{33}$.

EE quanta are without electrical charge and their current is maintained in *pq* by mutual q_{EE} gravity attraction is greater than attraction force of copper atom nucleus. Available physical data on copper and the proposed resistance model allow the calculation of approximate *pq* attraction force by determined EE quanta density and wire thickness.

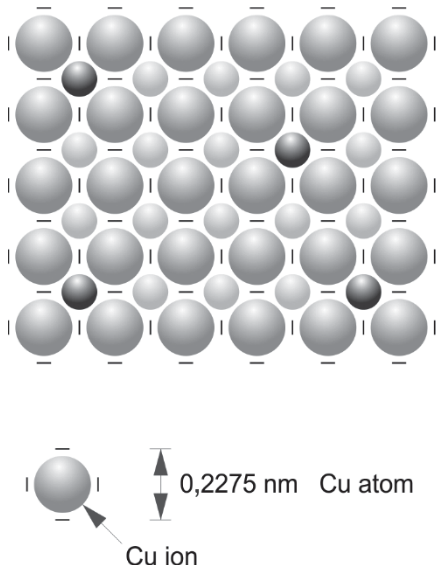

Figure 1 Segment of wire cross section with apparent sections of copper atoms, ions and interstitial quanta-paths (pq), some with oxygen atoms. The calculated section of atom lattice space is marked with 4 dashes representing 4 FE vibration amplitude planes.

Resistance events occur by quanta velocity c. However, e_{Cu} and wire axis are not parallel, EE quanta axial travel paths lengths are > of 1 m. Assuming the average angle 45° of Cu atoms edges and wire axis, the average EE quanta travel time was deduced as

$$L_t = 1 + 1\cdot \sin 45 = 1,7071\,\mathrm{m}$$

and

$$t_t = \frac{1,7071}{c} \tag{7}$$

$$t_t = \frac{1,7071}{2,9979\cdot 10^{8}} = 0,5694\cdot 10^{8}\ \mathrm{s}$$

Considering the presented analysis, the resistance equation derived is:

$$R_c = \left[\frac{\left(S_s\cdot J^*\right) + n_A\cdot t_t}{h\cdot n_{hex}\cdot n_{CuV}}\right]\cdot\left(\frac{n_0}{n_{pq}}\right) \tag{8}$$

With: S_S - wire surface area, J^*- SB radiation flux density at T = 298 K (temperature of data in [1]), n_A- number of A/m2 of wire cross section area, t_t - quanta travel time per m of wire, h - Planck constant, n_{hex} – number of quanta per atom expansion by current 1 A, n_{CuV} number of Cu atoms in volume of 1 m wire, n_O - number of O atoms /wire cross section area and n_{pq} - number of quanta paths/ wire cross section area.

The term in square brackets in eq. (8) determines the resistance part of copper atoms expansion and in round brackets that of oxygen atoms.

Applying the parameters in eq. (8) for d_w=11,684 mm with $R = 0,1608\cdot 10^{-3}$ Ωm [1] and using eq. (6), $c_O = 0,00037$ wt. % is deduced for all [1] wires.

The wire content of oxygen in wire is not quoted in [1], wires with known resistance and O content are not within reach, as well. In Wikipedia, $c_O = 0.0001$ wt. % is quoted for OFHC copper wire with highest conductivity and 10 to 100 times lower conductivity is quoted for wires with higher oxygen content. The contents c_O=0,0001 and 0,00037 wt. % are at the limit of analytical accuracy. Assuming that [1] values are valid for $c_O \approx$ 0,0001 wt. % and that the small difference of both cited oxygen contents c_O = 0,00037 wt. % may be considered as indirect verification of eq. (8). A similar relative difference of calculated and quoted resistance would be obtained for every OFHC wire with higher oxygen content. The agreement may be considered as verification of correctness of eq. (8).

CONCLUSION

– The length of copper atom lattice place ed

$$d_{Cua} = \left[\frac{\left(m_{Cua} / _{Cua} \right)}{A^*} \right]^{1/3}$$

$$d_{Cua} = 0.2275 \text{ nm}$$

with m_{Cu}-copper atom weight, ρ_{Cu} – copper density and A- Avogadro number.

– Resistance is explained as conversion of axial EE current to heat radiation with scattering of EE quanta and electrons by expansion of Cu atoms and by O wire atoms.

– The derived resistance equation is

$$R_c = \left[\frac{\left(S_s \cdot J^* \right) + n_A \cdot t_t}{h \cdot n_{hex} \cdot n_{CuV}} \right] \cdot \left(\frac{n_0}{n_{pq}} \right)$$

and is valid for all in [1] wires by copper content 0.00037 wt. % O.

Acknowledgement

The author thanks Mija, Blaž and Rok Vodopivec for trust and support and Fevzi Kafexhiu for Figure 1.

LITERATURE

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Note: The responsible translator for the English language is F. Vodopivec, Ljubljana, Slovenia