Candidate of Sciences in Physics and Mathematics V.A. Rantsev - Kartinov.

Conclusion

And, of course, I would like to express my sincere gratitude and deep appreciation to my teachers, outstanding scientists, senior fellows, and colleagues at my previous job who have already passed away, to Academician A.P. Aleksandrov and Academician, Nobel Laureate in physics A.M. Prokhorov, who not only explained to me the scale of what I have discovered in physics and what to do next, but also the peculiarities of my

future fate: they told me: “Keep in mind, a person ahead of his time, waiting for its arrival in uncomfortable conditions and remember for life the following prophetic words of the great Russian scientist V.I. Vernadsky: “The whole history of science at every step shows that individuals were more right in their statements than entire corporations of scientists or hundreds and thousands of researchers adhering to prevailing views... Undoubtedly, in our time the most true, most correct, and deepest scientific worldview lies among some individual scientists or small groups of researchers whose opinions do not attract our attention or excite our dissatisfaction or denial." These instructions allowed me to withstand the blows of scientific fate and continue my scientific work.

In my heart, a memory will always be kept off my friend, a wonderful scientist, and just a wise man, PhD in Physics & Mathematics - Rumiantsev A. A.

Finally, I would like to express my heartfelt gratitude to PhD in Engineering V.M. Tiutiunnik and Candidate of Sciences in Physics and Mathematics V.A. Rantsev- Kartinov for the joint work on universal industrial modules of disintegrators/activators.

References

1. A.V. Kulakov, A.A. Rumiantsev. Spontaneous magnetization of plasma of quantum origin, Journal of Technical Physics, 1988, Volume 58, Issue 4, p. 657- 660.

2. A.V. Kulakov, E.V. Orlenko, A.A. Rumiantsev. Quantum exchange forces in condensed matter, Moscow, Nauka Publishing House, 1990.

3. A.V. Kulakov, A.A. Rumiantsev. Ball lightning as a quantum condensate, Reports of the Academy of Sciences of USSR, Physics, 1991. Volume 320, No.5, p. 103-1106.

4. A.V. Kulakov, V.M. Tiutiunnik. Solid phase plasma ultraviolet laser, International Journal of Advanced Research, 2017, Vol. 5(4), pp.271-273.

5. A.V. Kulakov, V.A. Rantsev-Kartinov. Experimental confirmation of the existence of plasma quantum condensate, Izvestia RAS. Energetics, 2015, No.1, p. 46-61.

6. A.V. Kulakov, A.A. Rumiantsev. Generation of high-energy particles by MPD shock turbulence, Journal of Technical Physics, 1979. Volume 49, Issue 10, p. 2127-2132

7. A.V. Kulakov. Quantum plasma condensate as a new source of electric energy. MHD - generator with plasma separation. International Journal of Advanced Research-2017 - Res. 5(8).2004-2011.

8. A.V. Kulakov. Quantum non-ideal plasma as a source of heat energy. Plasma fuel combustion International Journal of Current Research. - 2017.-Vol. 9. P.6. P.53361-53365.

9. V.A. Rantsev-Kartinov, A.V. Kulakov. Universal module of industrial disintegrators/activators, Utility Model Patent No. 161751, Bulletin of the Federal Service for Intellectual Property, Patents, and Trademarks No. 13, dated 05/10/2016

10. A.V. Kulakov, V.A. Rantsev-Kartinov. Eurasian patent for invention No. 029979 Device for a universal module of industrial disintegrators/activators June 29, 2018.

11. P.L. Kapitsa. Why is fame needed?, Priroda Magazine, 1994, No. 4 (944)

12. A.V. Kulakov, V.A. Rantsev-Kartinov, and V.M. Tiutiunnik. Application of universal multipurpose modules of industrial disintegrator-activators for the processing of cereals and potatoes into starch products International Journal of Advanced Researc.2017 Res 5(5).1759-1762

13. A.V. Kulakov. Quantum plasma condensate. Cold nuclear fusion. New nano- technologies. LAMBERT Academic Publishing. 2019

EXPERIMENTAL DETERMINATION OF THE THICKNESS OF THE SURFACE LAYER IN THE PHYSICS OF NANOSTRUCTURES

Yurov V.M.

Karaganda State University. named after E.A Buketov

Abstract. Atomically smooth surfaces of solids, especially semiconductors, are urgently needed to study the fundamental nature of surface phenomena. They are also needed in the manufacture of modern semiconductor devices. It is believed that only on atomically smooth surfaces can nanostructures be created that undergo crystal self-organization during crystal growth.

In this paper, we consider methods for experimental determination of the thickness of the surface layer, surface tension, and the melting temperature of nanostructures of dielectrics, magnetic materials, metals, and alloys.

The X-ray luminescence intensity of dielectrics was determined by the standard photoelectric method. Specific magnetization was measured using a vibrating magnetometer. The electrical conductivity of a metal or alloy film was determined using a standard three-electrode circuit.

The use of Patents and utility model descriptions for patents provides simple formulas for calculating or experimentally determining the thickness of the surface layer, surface tension and the melting temperature of

nanostructures of dielectrics, magnetic materials, metals and alloys. The experimental determination of these values will allow you to control the technological processes of obtaining nanomaterials from any materials with desired properties.

Keywords. Surface tension, surface layer thickness, size effect, melting point, nanostructure.

Introduction. Atomically smooth surfaces of solids, especially semiconductors, are urgently needed to study the fundamental nature of surface phenomena [1-4]. They are also needed in the manufacture of modern semiconductor devices [5]. It is believed that only on atomically smooth surfaces can nanostructures be created that undergo crystal self-organization during crystal growth [6, 7]. The atomic-smooth surfaces of solids began to be studied recently because of the rapid growth of nanotechnology (see, for example, [8–10]).

In this post, we consider atomically smooth nanostructures based on our works [11, 12], paying attention to Patents.

Description of the model. In [11], the proposed model of the surface layer of atomically smooth metals is generalized. The surface layer of an atomically smooth metal consists of two layers - d(I) and d(II). A layer with h = d is called layer (I), and a layer at h≈10d is called layer (II) of an atomically smooth crystal. At h≈10d, the size dependence of the physical properties of the material begins to appear. To determine the thickness of the surface layer, we used the size dependence of the physical property A(r) [11]:

$$A(r) = A_0 \cdot (1 - \mathrm{d}/\mathrm{r}), r >> \mathrm{d}, A(r) = A_0 \cdot (1 - \mathrm{d}/\mathrm{d} + r), r \leq \mathrm{d}. \quad (1)$$

The parameter d is related to the surface tension σ by the formula:

$$d = 2\sigma\upsilon/\mathrm{RT}. \quad (2)$$

Here σ is the surface tension of a massive sample; υ is the volume of one mole; R is the gas constant; T is the temperature. It was shown in [11] that, to within 3%,:

$$\sigma = 0{,}7 \cdot 10^{-3} \cdot T_m, \quad (3)$$

where T_m is the melting point of a solid (K). The ratio holds for all metals and for crystalline compounds. At $T = T_m$, we obtain:

$$d(I) = 0{,}17 \cdot 10^{-3}\upsilon. \quad (4)$$

Equation (4) shows that the thickness of the surface layer d (I) is determined by one fundamental parameter - the molar (atomic) volume of the element (υ = M/ρ, M is the molar mass (g/mol), ρ is the density (g/cm^3).

For a number of metals, the value of d(I) is presented in table. 1.

The thickness of the surface layer d(I) of pure metals at a temperature close to the melting temperature ranges from 0.8 nm (Be) to 12.1 (Cs) nm, i.e. refers to the nanostructure. This layer thickness can be experimentally determined by the method of sliding scattering of x-rays in internal reflection. For gold, this layer thickness is 1.2 nm at room temperature [13], which coincides with thermal expansion with its value from the table. 1 - d(I) = 1.7 nm.

Table 1

The thickness of the surface layer d(I) of some pure metals (Me)

Me	d(I), nm	Me	d(I), nm	Me	d(I), nm	Me	d(I), nm	Me	d(I), nm	Me	d(I), nm
Li	2,2	Sr	5,9	Sn	2,8	Cd	3,4	Fe	1,2	Gd	3,4
Na	4,5	Ba	6,6	Pb	3,1	Hg	1,8	Co	1,1	Tb	3,3
K	7,7	Al	1,6	Se	2,8	Cr	1,2	Ni	1,1	Dy	3,3
Rb	10,0	Ga	2,0	Te	3,5	Mo	1,8	Ce	3,6	Ho	3,2
Cs	12,1	In	2,7	Cu	1,2	W	1,6	Pr	3,5	Er	3,2
Be	0,8	Tl	2,4	Ag	1,7	Mn	1,1	Nd	3,4	Tm	3,1
Mg	2,4	Si	2,1	Au	1,7	Tc	1,4	Sm	3,4	Yb	4,2
Ca	4,4	Ge	2,4	Zn	1,6	Re	1,5	Eu	5,0	Lu	3,0

In the d(I) layer with pure metal atoms, reconstruction and relaxation associated with surface rearrangement occur [13]. For gold, the lattice constant is a = 0.41 nm and the surface is rearranged at a distance of three atomic monolayers.

Determination of the thickness of the surface layer, surface tension, and the melting temperature of dielectric nanostructures [14–16].

The method was used to determine the surface tension of dielectric KCl crystals. The X-ray luminescence intensity was determined by the standard photoelectric method. The dielectric grain size was determined using a MIM-8 type metallographic microscope. The results are shown in Figure 1.

In the coordinates A(r) = I ~ 1/r, the experimental curve is straightened in accordance with (1), giving a value of d = 6.4 nm. For KCl, υ = 37.63 cm3 / mol and from (2) for surface tension it was obtained: σ = 0.734 J/m^2. A value of d = 6.4 nm gives us a thickness of d(I). Substituting the parameter d into formula (1) and taking the value of T0 from the reference book, we determine the melting temperature of KCl nanoparticles. The results for KCl nanoparticles of various radii are given in table. 1. Particles r = 1 nm of potassium chloride are unstable at room temperature (300 K). Using the claimed method will allow to control the technological processes of obtaining dielectric materials of micro - and nanoelectronics with desired properties and products from them.

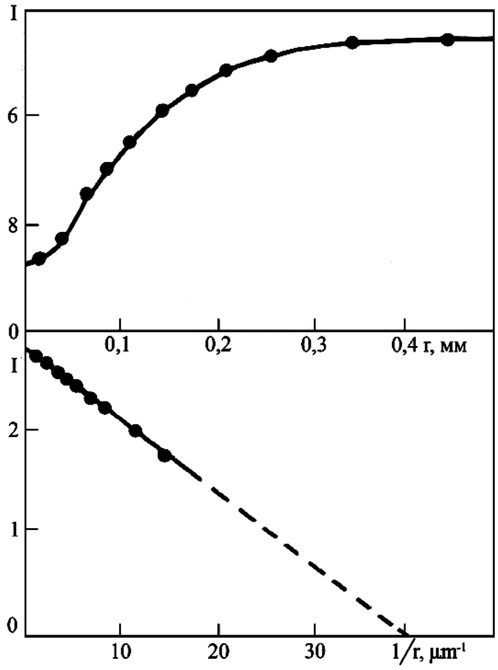

Figure 1 - Dependence of the intensity of X-ray luminescence KCl on the grain size of the phosphor

Table 1 - Melting point of KCl nanoparticles

dielectric	T_0, K	d, nm	T(r), K r = 1 nm	T(r), K r = 10 nm	T(r), K r = 50 nm
KCl	1043	6,4	208,6	745,0	965,7

Determination of the thickness of the surface layer and the surface tension of magnetic nanostructures [17, 18]. In this case, the measured surface tangent of the magnetic susceptibility of the magnetic material versus the inverse radius of its particles calculates its surface tension. The dependence of the magnetic susceptibility of the magnetic material on the particle size is also described by formulas (1) and (2). The constructed dependence in the coordinates A(r)=æ (is the inverse radius of particles, magnetic material), we obtain a straight line, the tangent of the angle of inclination, which determines d, and the surface tension of the magnetic material (σ) is calculated by formula (2). The method was used to determine the surface tension of magnetites of the Sokolovsky deposits. Specific magnetization was measured using a vibrating magnetometer. The grain size of magnetite was determined using a metallographic microscope. The results are shown in fig. 2. In coordinates æ, the experimental curve is straightened in accordance with formula (1), giving a value of d=0.36 μm. For magnetite υ=44.5 cm^3/mol, and from relation (2) for surface tension it was obtained: σ=10.1 10^3 erg/cm.

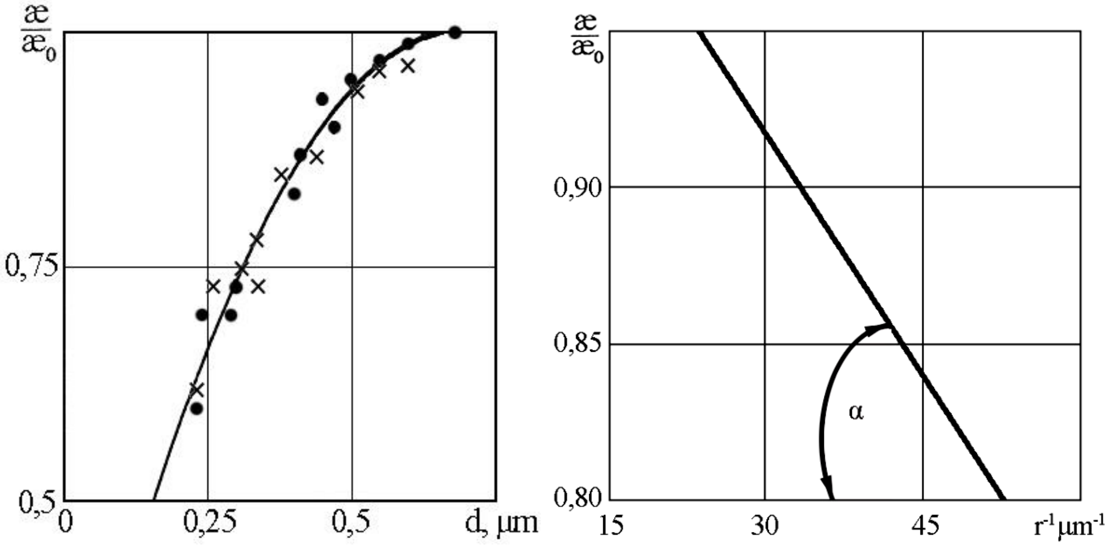

Figure 2 Relative magnetic permeability versus radius (a) and inverse radius (b) of magnetite particles

Calculations using the formulas of the theory of magnetism using experimental values of saturation magnetization yielded a value of σ = 10.1 10^3 erg/cm, which practically coincides with the above. The formulas of the theory of magnetism, however, are applicable for a limited number of materials, while the proposed method allows one to determine σ experimentally for any magnetic minerals.

Determination of the thickness of the surface layer and the melting temperature of nanostructures of metals and alloys [19-21].

The dependence of the electrical conductivity σ and the dielectric constant ε of the material on the film thickness h is also described by a formula of the type (1) (Figure 3). The constructed dependence in the coordinates A(r) = σ ~ 1/h(1/h is the inverse thickness of the metal or alloy film) is a straight line, the slope that determines d - the thickness of the surface layer of the metal or alloy. The proposed method has no analogues and allows you to determine the most important characteristic of metals and alloys - the thickness of the surface layer, which determines the operational properties of metals and alloys and products from them, allows you to purposefully create new structural materials.

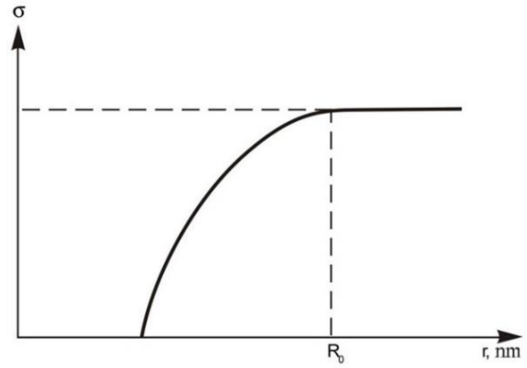

Figure 3 - Generalized dependence of electrical conductivity on the size of a small particle

The method was used to determine the thickness of the surface layer of metals: copper, zinc, aluminum, tin, lead, gold, silver and alloys: 10% copper-90% tin. 20% zinc-80% aluminum, 15% tin- 85% lead.

A metal or alloy film was deposited thermally in vacuum on a VUP-5 vacuum unit on a quartz one. Film thickness was determined using a JEOL JSM-5910 microscope. The electrical conductivity of the metal film was determined using a standard three-electrode circuit, or by the method of [22]. The results of determining the thickness of the surface layer are given in table. 2.

The melting point of a nanoparticle of radius R is determined by the formula:

$$T(R) = T_0 \cdot \left(1 - \frac{d}{d+R}\right), \qquad (5)$$

where T_0 is the melting temperature of a massive sample of a metal or alloy, which is experimentally determined for all pure metals and for most alloys and is presented in numerous reference books. The method was used to determine the melting temperature of metal nanoparticles: zinc, aluminum, tin, lead, copper, gold, silver. Substituting the parameter d from Table 2 into formula (5) and taking the value of T_0 from the directory, we determine the melting point of the metal nanoparticles. The results for nanoparticles of various radii are given in table. 3.

Table 2

The thickness of the surface layer of metals and alloys

Metal or alloy	d, nm	Metal or alloy	d, nm
Cu	1,2	Au	1,7
Zn	1,6	Ag	1,7
Al	1,6	10 % Cu-90% Sn	2,03
Sn	2,8	20% Zn-80% Al	2,06
Pb	3.1	15% Sn- 85% Pb	2,51

Table 3

The melting point of pure metal nanoparticles

Metal	T_0, K	d, nm	T(R), K R = 1 nm	T(R), K R = 10 nm	T(R), K R = 50 nm
Zn	693	1,6	277,2	602,6	672,8
Al	933	1,6	291,6	764,8	933,0
Sn	505	2,8	168,3	420,8	485,6
Pb	600	3,1	166,7	600,0	600,0
Cu	1356	1,2	411,0	1102,4	1296,4
Ag	1234	1,7	301,0	942,0	1162,0
Au	1336	1,7	310,7	1004,5	1253,3

In the widely known and often cited paper [23], an experimental value of the melting temperature of 305–310 K was obtained for gold nanoparticles 1 nm in size, which practically coincides with our value. This is in favor of the proposed method for determining the melting temperature of nanoparticles.

Using the claimed method will allow to control the technological processes of obtaining nanomaterials from metals and alloys with desired properties.

Conclusion

The use of Patents and the utility model descriptions for a patent [14-21] provides simple formulas for calculating or experimentally determining the thickness of the surface layer, surface tension and the melting temperature of nanostructures of dielectrics, magnetic materials, metals and alloys. The experimental determination of these values will allow you to control the technological processes of obtaining nanomaterials from any materials with desired properties. Further research prospects relate to the study of physical and chemical processes in nanostructures of various compositions.

The work was carried out under the program of the Ministry of Education and Science of the Republic of Kazakhstan. Grants No. 0118РК000063 and No. Ф.0781.

References

1. Li J., Schneider W.-D., Berndt R., Crampin S.. Electron confinement to nanoscale Ag islands on Ag(111): a quantitative study. // Phys. Rev. Lett. – 1998, V. 80. - P. 3332-3335.

2. Stipe B.C., Rezaei M.A., Ho W.. Inducing and viewing the rotational motion of a single molecule. // Sci. Rep., 1998, V. 279. - P. 1907-1909.

3. Kalff F.E., Rebergen M.P., Fahrenfort E., Girovsky J., Toskovic R., Lado J.L., Fernandez-Rossier J., Otte A.F. A kilobyte rewritable atomic memory. // Nat. Nanotechnol. Lett., 2016, V. 11. - P. 926-930.

4. Drost R., Ojanen T., Harju A., Liljeroth P. Topological states in engineered atomic lattices. // Nat. Phys. Lett., 2017, V. 13. - P. 668-672.

5. Karkare S., Bazarov I.. Effects of surface nonuniformities on the mean transverse energy from photocathodes. // Phys. Rev. Appl., 2015, V. 4. - P. 024015.

6. Teichert C. Self-organization of nanostructures in semiconductor heteroepitaxy. // Phys. Rep., 2002, V. 365. - P. 335-432.

7. Xu F., Huang P.W., Huang J.H., Lee W.N., Chin T.S., Ku H.C., Du Y.W.. Self-assembly and magnetic properties of MnAs nanowires on GaAs(001) substrate. // J. Appl. Phys., 2010, V. 107. - P. 063909.

8. Odinokova E.V., Panfilov Yu.V., Yurchenko P.I. Prospects for obtaining nanometer surface roughness by the ion beam method. // Engineering Journal: Science and Innovation, 2013, no. 6. URL: http://engjournal.ru/catalog/nano/hidden/801.html.

9. Zakharov P.V., Korznikova E.A., Dmitriev S.V. Discrete breathers near the surface of the Pt_3Al intermetallic alloy // Materials Physics and Mechanics, 2017, V. 33. - P. 69-79.

10. Kazantsev D.M. Modeling of processes of thermal smoothing and disordering of the surface of semiconductors. - Diss. Candidate Phys.-Math. Sciences, Novosibirsk, 2018 .-- 112 p.

11. Yurov V.M. The thickness of the surface layer of atomically smooth crystals // Physicochemical aspects of the study of clusters, nanostructures and nanomaterials, 2019, Vol. 11. - P. 389-397.

12. Yurov V.M. The inverse Hall-Petch effect in atomically smooth metals // LXVI International Scientific Readings (in memory of L.D. Landau): a collection of articles at the International Scientific and Practical Conference (Moscow, 02.22.2020). - Moscow: EFIR, 2020. - P. 17-22.

13. Oura K., Lifshits V.G., Saranin A.A., Zotov A.V., Katayama M. .. Introduction to surface physics. M .: Nauka, 2006. - 490 p.

14. Yurov V.M., Portnov V.S., Puzeeva M.P. A method of measuring surface tension and density of surface states of dielectrics. Pat. 58155, Republic of Kazakhstan, publ. 12/15/2008, Bull. Number 12.

15. Yurov V.M., Guchenko S.A., Laurinas V.Ch., Zavatskaya O.N. Method for measuring the thickness of the surface layer of dielectrics // Description of the utility model for the patent, No. 3748, Publ. 03/07/2019, bull. No. 10.

16. Yurov V.M., Guchenko S.A., Laurinas V.Ch., Zavatskaya O.N. A method for determining the melting temperature of dielectric nanoparticles // Description of the utility model for the patent, No. 3749, Publ. 03/07/2019, bull. Number 10.

17. Yurov V.M., Portnov V.S., Puzeeva M.P. A method of measuring the surface tension of magnetic materials. Pat. 58158 Republic of Kazakhstan. Publ. 12/15/2008, Bull. Number 12.

18. Yurov V.M., Guchenko S.A., Laurinas V.Ch. A method of measuring the thickness of the surface layer of magnetic materials // Description of the utility model for the patent, No. 3747, Publ. 03/07/2019, bull. No. 10.

19. Yurov V.M., Guchenko S.A., Ibraev N.Kh. A method of measuring the surface tension of deposited coatings. Pat. 66095 Republic of Kazakhstan, publ. 11/15/2010, Bull. Number 11.

20. Yurov V.M., Guchenko S.A., Laurinas V.Ch. The method of measuring the thickness of the surface layer of metals and alloys // Description of the utility model for the patent, No. 3751, Publ. 03/07/2019, bull. No. 10.

21. Yurov V.M., Guchenko S.A., Laurinas V.Ch., Zavatskaya O.N. A method for determining the melting temperature of nanoparticles of metals and alloys // Description of the utility model for the patent, No. 3750, Publ. 03/07/2019, bull. Number 10.

22. Surin Yu.V., Shimko V.N., Matveev V.V. Non-contact method for measuring the resistivity of wafers of semiconductors and epitaxial layers // Zavodskaya Lab, 1966, v.32, No. 9. - P.1086-1088.

23. Buffat Ph., Borel J.-P. Size effect on the melting temperature of gold particles // Phys. Rev. A, 1976, V.13, №6. – P. 2287-2298.