Research of acoustically stimulated thermal desorption in electrovacuum microwave devices

To cite this article: I F Khanbekov et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 387 012032

View the article online for updates and enhancements.
Research of acoustically stimulated thermal desorption in electrovacuum microwave devices

I F Khanbekov\textsuperscript{1,2}, I P Li\textsuperscript{1}, V S Petrov\textsuperscript{1}, V P Mikhaylov\textsuperscript{2} and E A Deulin\textsuperscript{2}

\textsuperscript{1}JSC Pluton, 105120, Moscow, Russian Federation
\textsuperscript{2}Bauman Moscow State University, 105005, Moscow, Russian Federation

E-mail: ivan.khan@ya.ru, mikh-vp@yandex.ru

Abstract. The article describes the results of the research of gas desorption from internal surfaces and from the thickness of metal and non-metal parts of electrovacuum microwave devices into free gas due to the simultaneous thermal and acoustic effects on the device body. There are adduced the comparison of the rate of gas release at different technologies of electric devices pumping. Also, it’s given the physical explanation of the mechanism of thermoacoustic desorption of gas components in a vacuum. Also, it’s given the physical explanation of the mechanism of thermoacoustic desorption of gas components in a vacuum.

A degassing process of electrovacuum microwave devices is the most prolonged technological process, which is connected with high energy consumption and high responsibility. During a degassing process the working capacity of the whole product is being formed. Nowadays not enough attention is paid to degassing process of electrovacuum microwave devices. Often the technology hasn’t changed since the moment of the development, despite that the last 30–40 years the perceptible progress in the field of vacuum technology has occurred. The electrovacuum microwave device degassing process occurs according to classical scheme with using a step heating of product housing and with isothermal holding at a temperature about 550 °C. The duration of this process could reach several dozens of hours. Obviously, it is impossible to accelerate the degassing process of electrovacuum devices using the classical technology inasmuch that thermal desorption capabilities are exhausted in this cause and the further increasing of a temperature will case a damage or destruction of electrovacuum microwave elements. An application of pumps which are more powerful will increase the sizes of operating units. It is also connected with larger financial investments. Herewith, using more powerful pumps will allow increasing degassing velocity insignificantly, which is limited with exhaust tube capacity in this case. An application of non-thermal desorption types could be more effective way to accelerate degassing process of electrovacuum microwave devices. It allows to intensify gas separation. Considering all existing types of desorption we can distinguish an acoustic desorption, more precisely – an acoustically stimulated thermal desorption. This method is the most appropriate. It is easy to implement and doesn’t require large financial costs. That why it allows to increase the efficiency of degassing of devices significantly.

The mechanism of an acoustically stimulated thermal desorption is rather complicated and consists of several simultaneous processes, with the advantages desorption acceleration and acceleration of a vacuum pumping process of gas components from a vacuum volume of electrovacuum microwave devices. An increasing thermal desorption intensity with using acoustic fluctuations could occur due to...
stimulation of a separation colloidal particles from surfaces inside the vacuum volume at the expense of its mechanical acceleration. It is known that the process of degassing device walls is parallel to the process of shaking off microscopic coarse-colloid particles from the inside walls of the device to a certain degree. Actually a significant quantity of foreign particles is located on all components of inside fittings of an item. They don’t only slow down vacuum degassing process by closing surface areas by themselves, but they also appear as sources of gas flows. Another factor of accelerating degassing of electro vacuum microwave devices is directional speed up of desorbed molecules motion of a non-associated gas by an acoustic-surface-wave (ASW) which is spreading from degassed volume to lower pressure side. This effect is described in the sources [2, 3].

Presumably, the main mechanism of intensifying the gas components desorption is the compression and tension of the metal crystal lattice and deformation of intercrystalline gaps, caused by acoustic vibrations of the polycrystalline metal structure.

The one mechanism of the previously described acoustically stimulated thermal desorption is the closing and opening of intercrystalline gaps, which are “open” to atoms (primarily hydrogen) in the case when the walls of intercrystalline gaps are covered with at least one monolayer of sorbate with high volumetric concentration $C_{S1}$ (figure 1(a), right). Acoustic oscillations are closing the intercrystalline gaps (figure 1(b), right) and causing instantaneous connection of sorbate layers on the gaps walls, simultaneously causing heating in the area of the newly formed contact (figure 1(b), left) up to temperature $TS1=TS2$, because sorption is an exothermic process. In our case we are dealing with “collective sorption” and the contact of “groups” of molecules located on opposite surfaces [5].

![Figure 1](image-url)  
*Figure 1. View plots of the distribution of temperatures $T_S$ and volume concentrations $C_S$ of the gases atoms in the acoustic vibration intercrystalline gaps.*

This “collective sorption” process occurs at ultrasonic frequency and at the nanoscale distances. The result of this process is instant local heating of the polycrystalline structure of the acoustically stimulated material (figure 1(c), (d), left). Herewith, the diffusion processes take place both deep in the...
metal crystal lattice nto the and on the surfaces of the intergranular boundaries, by stretching and compressing the crystal lattice. Finally, the described repeated a high frequency process with leads to the appearance of pulses of the gas flow (Qd) from the gap (figure 1(f), right). At this point, the material is not heated (temperature TS curve 10 in figure 1(f), left), because the desorption process comes with heat absorption.

The result is the appearance of a gas release flow (Qd) from the gaps between the crystallites, as shown in figure 2. Hence, schematically the acoustically stimulated thermodesorption can be represented as the process movement of thermally activated atoms in shrinking and stretching crystal lattice of metal, located in the acoustic field, and process "collective" sorption, causing the pulsed local heating of the crystallites surfaces.

Consider the scheme of hydrogen gas evolution from the surface layer of the polycrystalline structure of corrosion-resistant steel (figure 2) when exposed to ultrasonic vibrations [6, 7]. As shown in figure 2, crystallite sizes are in a fairly wide range from units to tens of micrometers, the intergranular boundaries width is from tens to tens of angstroms. Precisely in these intergranular boundaries, the gas sorbed on the surfaces of crystals and dissolved in the metal volume is mainly located [8–10]. Under the influence of longitudinal and transverse ultrasonic vibrations on crystallites there are forced elastic vibrations. In this case, the width of the intercrystalline boundaries also changes with the frequency of forced oscillations. Under certain conditions, there is a sharp increase in the amplitude of the elastic oscillations of the width of the boundaries between the crystals. In this case, the pulsed local heating of the surface of crystallites occurs and the mobility of "dissolved" hydrogen atoms is increased, as described above. The gas "dissolved" in the intergranular boundaries and the volume of grains diffuses to the surface adjacent to the vacuum medium, where its concentration in conditions of ultra-high vacuum is close to zero, and then it is desorbed and pumped out by the vacuum system.

\[ q_i = \frac{8dN_0}{\pi^2} \left( 1 - e^{-\frac{Dn^2}{4d^2}t} \right), \]  
(1)

where \(d\) – is a half the thickness of the metal part; \(N_0\) – the initial molecular concentration of the gas in the metal; \(D\) – the diffusion coefficient of the gas in the metal.

The gas diffusion coefficient in the metal is determined as follows:

\[ D = \frac{1}{6} a \cdot \bar{u} \cdot e^{-\frac{E}{RT}}, \]  
(2)

**Figure 2.** Scheme of gas release from the surface layer of polycrystalline structure corrosion-resistant steel.

The specific gas flow \(q_i\) (figure 2) of the thickness of the material is limited by the diffusion process, which in this case is described by the second Fick law:
where \( a \) – constant of a crystal lattice of metal; \( \bar{u} \) – average thermal velocity of atoms; \( E \) – heat or activation energy of gas diffusion.

The efficiency of an acoustically stimulated thermal desorption has been proved experimentally. The essence of the experiments was in registration a gas components pressure increasing in a previously degassed volume of electrovacuum microwave device till \( 1 \times 10^{-7} \) Torr. In the first case trials were conducted without a heating of product housing. On the graphic chart (figure 3) there is a time dependence of residual gases pressure increasing in a volume of magnetron after a vacuum pump disconnection. The curve 1 shows a pressure increasing without an acoustic influence, the curve 2 – with an acoustic influence, accordingly. Point a and b denotes conditionally an identic saturation of vacuum volume with desorbed gases for the different time.

![Figure 3](image-url)

**Figure 3.** Graphic chart of a time dependence of residual gases pressure increasing in a volume of a magnetron: 1 – graph without ultrasonic; 2 – graph with ultrasonic.

In the second case a heat up of magnetron housing was added to a similar trial. On the graphic chart (figure 4) a residual gases pressure increasing in a volume of a magnetron is shown with increasing the temperature according to the linear law with a speed of 9 °C/min in the range of 20°-393 °C. The peak emission of desorbed molecules during a thermal desorption, peak a) will appear after 37.5 min. at the

![Figure 4](image-url)

**Figure 4.** Graphic chart of a time dependence of residual gases pressure increasing in a volume of magnetron with a heat up: 1 – graph without ultrasonic; 2 – graph with ultrasonic.
temperature 357 °C (1 – graph without ultrasonic). And during the acoustically stimulated thermal desorption peak b), will appear after 17.7 min. at the temperature 182 °C (2 – graph with ultrasonic). Therefore the duration of vacuum pumping out is reduced 2.12 times and the temperature of the effective water molecules desorption is reduced by 175 °C or 2 times [4].

Thereby we can draw a conclusion about the efficiency of an acoustically stimulated thermal desorption. Obviously suchlike decision allows to increase an intensity of gas components desorption and diffusion from the inside parts of machined product, reduce the electrovacuum devices degassing time duration and therefore to increase volumes of finished products output.

**Acknowledgment**

The authors express their grace to Maxim A Naumov and Alexey V Glushenkov for the assistance in the preparation of this article.

**References**

[1] Ostroumov G A and Fedotov G A 1973 Acoustic journal 1 76–9
[2] Makarov A, Luskinovich P N and Ryzhikov A 1997 Method of pumping gases and vacuum pump for pumping gases. RF patent for the invention № 2079000
[3] Aitkhozhin A 1995 Method of high vacuum pumping and pump for its implementation. Application for invention № 95105038
[4] Lee P, Lifanov N D, Petrov S, Hanbekov F, Kotlicki I Yu, Alenkov I, Zabelin A N, Sugars A 2018 Patent RU 2 644 553
[5] Deulin E A 2018 Physics of vacuum mechanics
[6] Kudryashov B A, Grib V V, Gaevskii V V, Dem’yanushko I V, Kartsov S K 2017 Russian Engineering Research 12 1081–3
[7] Dem’yanushko I V, Kazantsev V F, Karagodin V I, Luzhnov Y M, Prikhod’ko V M 2017 Russian Engineering Research 12 1084–6
[8] Komshina A V, Pomel’nikova A S and Fetisov G P 2015 Russian Metallurgy 13 1158–60
[9] Alexander P, Andrey P, Alexander N and Elena N 2015 Defect and Diffusion Forum 363 142–7
[10] Kurkin A S, Makarov E L, Kurkin A B, Rubtsov D E and Rubtsov M E 2017 Metal Science and Heat Treatment 3–4 250–4