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Intermetallic Getters Reactants for Vacuum Applications

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Abstract

The present work continues a series of publications devoted to the study of the sorption properties of reactive alloys based on IIA metals and the development of advanced getter materials for gas and vacuum technologies. This publication attempts to answer the current challenges in the field of gas sorption associated with the emergence of new vacuum products such as vacuum insulated glasses, electronic systems, cryogenic devices, etc. An analysis of the problems that arise here, as well as the results of sorption measurements, carried out with the participation of intermetallic phases of the composition $CaLi_2$ and $Ca_{0.33}Li_{0.48}Mg_{0.19}$, show that the best getter support for these new hermetically sealed products can be provided by intermetallic compounds formed in systems Li-IIA metals. Intermetallic phases of this family are easy to manufacture and demonstrate outstanding service characteristics: their specific sorption capacity is recorded high, exceeding traditional gas sorbents in this respect by at least an order of magnitude; the kinetics of gas capturing is set at the stage of alloy production, *i.e.*, is adjustable; the temporary resistance of these phases to atmospheric gases allows to install the getter at its workplace in air, without further thermal activation. The sorption superiority of reactive intermetallics is explained by their special sorption mechanism: the gas/metal interaction is formed here as a combination of two processes, continuous growth of reaction products on a metallic surface and corrosion decay of brittle intermetallic phase under mechanical forces, which feeds the chemical reaction with a fresh surface. The advantages of sorption processes of this new type are undoubted and significant: compared with the conventional sorbents, an intermetallic getter reactant solves two important problems; it reduces production costs and increases the sorption yield.

Keywords

Vacuum Devices, Gas Sorption, Getters, Intermetallic Phases, Corrosion

1. Introduction

The problems connected with the sorption of gases affect the interests of many technologies, both those that are directly related to the gas industry, and those that aim to achieve vacuum. Gas sorbents themselves are a large group of different materials that solve different sorption problems under different conditions. However, they are united by a number of common requirements imposed on them by applications; this is the maximum possible sorption capacity, low production costs and temporary resistance to the environment, for example, to air at the stage of introducing the sorbent into its working position.

The last point of the requirements actually turned out to be a priority, since only sorbents that are ready for an open (*i.e.* in the air) transfer into a target hermetic shell, for example, such as a vacuum chamber, a sorption column, or hermetically sealed electronic device, are of practical interest. Such sorbents really simplify the assembly technology, and their development is reduced to the choice of a sorbent material capable of protecting itself from gases by the formation of a relatively thin layer of reaction products on the surface [1] [2] [3], or to the creation of a new material consisting of a mixture of solid particles of a known sorbent and a handling agent in the form of a liquid filler [4] [5] [6] [7]. A known sorbent here refers to representatives of one of the three classes of gas sorbents, adsorbents, chemisorbents (they are also called getters) and absorbents.

A disadvantage of traditional sorbents is their low specific sorption capacity, which is explained by their chemical nature [8], by an increase in the volume fraction of the sacrificial layer with an increase in the specific surface area of the sorbent [9], by a decrease in the volume fraction of the sorbent when it is mixed with a filler [5], and, finally, by thermal activation [3] [9]. The thermal activation causes severe damage to the sorbent by poisoning it when the vacuum chamber is heated during degassing.

Another class of sorbents is pure IIA metals. These metals react with gases at T_{room} to the end, until they turn into chemical compounds, where there are several gas atoms per one metal atom [10] [11] [12] [13], which are unthinkable when using the familiar adsorbents. However, these metals also have weak points, such as their sorption selectivity, toxicity of some of them, excessively high chemical activity in the form of powders or films, etc.

All this hinders the mass production of such a popular today product as vacuum insulating glass (VIG), this is what reduces the reliability and service life of such products as MEMS devices and electronic systems, this is the reason for the high costs in natural gas purification technologies, as well as purge and shield gases such as nitrogen, argon, etc. There is no doubt that with the help of successful engineering solutions, local achievements in the field of sorption technologies will continue in the future. However, a large-scale breakthrough here is possible only with the advent of a new sorbent, which would be unlimitedly available, practically convenient, and many times superior to existing sorbents in terms of specific sorption capacity.

A real contender for such a new sorbent are getters reactants—binary, ternary, and quaternary Ca, Li, Mg, and Sr alloys, made in the form of bodies of various shapes and sizes, but with a monolithic structure [3]. The methods for obtaining such sorbents are described below, and the results of sorption measurements are presented, demonstrating an unattainably high level of sorption capacity of these materials compared to those currently used.

2. Alloy Preparation Methods

Alloys of IIA metals, with or without Li, are reactive and also volatile already at relatively low temperatures, starting from 300˚C and higher, which leaves its mark on the methods of their melting and subsequent processing. Let us describe two simple time-tested methods for the manufacture of such alloys.

In one of them, a crucible is loaded with the alloy components under the Ar into glove box with a vertical Antechamber (**Figure 1**). This design of the box is a forced measure imposed by the procedure for transferring an elongated cylindrical crucible with a reactive charge to the growth furnace (**Figure 2**) under conditions of isolation from the atmosphere. This crucible is transferred to the furnace in a refractory steel container with a gate valve and then the furnace is lifted so that the container enters the furnace channel.

The argon is removed and the vacuum level in the container is brought to 10^{-6} mbar by gradually raising the furnace temperature to 250˚C - 280˚C. After degassing, argon is introduced at a pressure from 1 to 5 mbar depending on the composition of the charge and the temperature in the furnace is raised to $T_f +$ 50˚C, where T_f is the melting point of the most refractory component. The state of the charge in the crucible is observed visually through a vacuum window in the upper part of the growth column (**Figure 2**), which makes it possible to monitor all changes in the process of melting and solidification of the sample.

In another method, a thin-walled SS 304 tube, with a hermetically sealed end, replaces a crucible and container. After filling the tube with the charge in the glove box under Ar, it is connected to the vacuum valve via adapter, taken out of the glovebox, connected to the vacuum system and after the degassing of the charge at the same 250˚C - 280˚C, the tube is inserted into the apparatus for pinching and cutting under pumping out (**Figure 3**). The product of the given procedure is a metal ampoule with the charge under vacuum (**Figure 4**). The ampoule is placed in a furnace and the required temperature is set for growing the ingot.

Reactive ingots are ready for direct use as sorbents in gas purification technologies [16], while in vacuum applications their additional processing is required to give them the shape of granules, wire, ribbons, or tablets. Eutectic alloys $(Ca_xSr_{1-x})_yMg_{1-y}$ including those alloyed with lithium, where $0 \le x \le 1$, $0.65 \le y \le 0.75$, allow processing by rolling, forging and cutting at low heating in an inert or dry atmosphere. However, for intermetallic phases, especially with a high

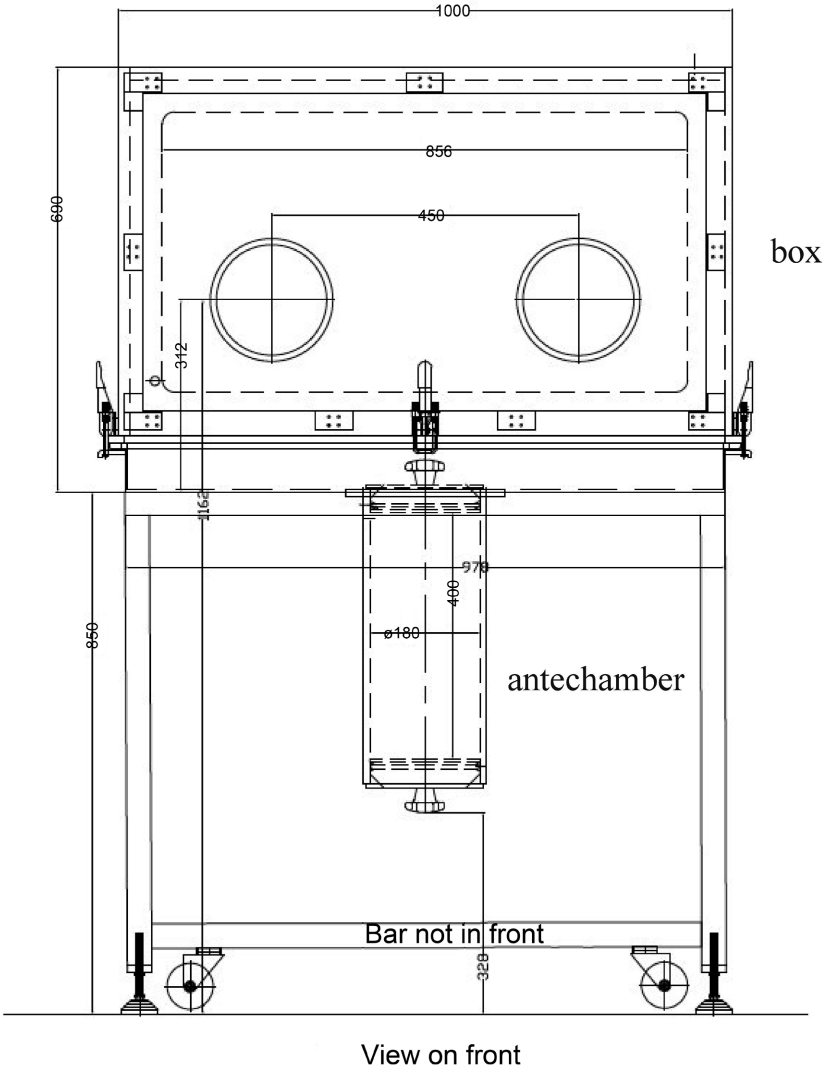


Figure 1. Glove box, drawing, frontal projection.

Figure 2. Growth station.

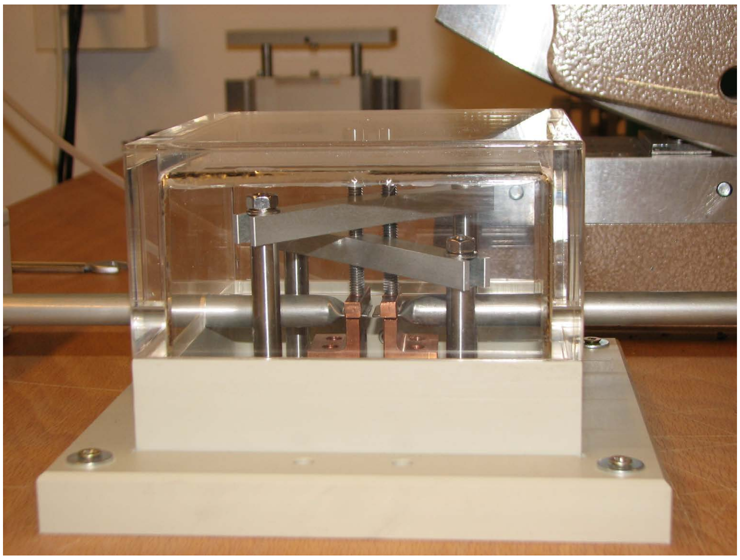


Figure 3. Argon chamber for sealing off metal tube by short circuit method under vacuum [14] [15].

Figure 4. Vacuum sealed SS ampoules.

fraction of lithium, e.g. $CaLi_2$, Li_3Sr_2, $Li_{23}Sr_6$, $BaLi_4$, as well as ternary alloys of composition $Ca_{0.33}Li_xMg_{0.67-x}$, where $0.45 \le x \le 0.55$ and which are characterized by brittleness and low melting point only methods of casting in vacuum according to a given shape are suitable.

In this work ingots of two alloys related to Laves phases were fabricated, these are the $Ca_{0.33}Li_{0.48}Mg_{0.19}$ ternary alloy and the $CaLi_2$ compound. Metals with a purity of 99.9% from Alfa Aesar were used as the starting material. The resulting ingots were dissected in a glove box under argon to get samples with small mass. The samples were then weighed under Ar to determine their initial weight and transferred to a laminar cabinet (**Figure 5**). This latter served as the place where the entire subsequent procedure of weight measurements was carried out in the

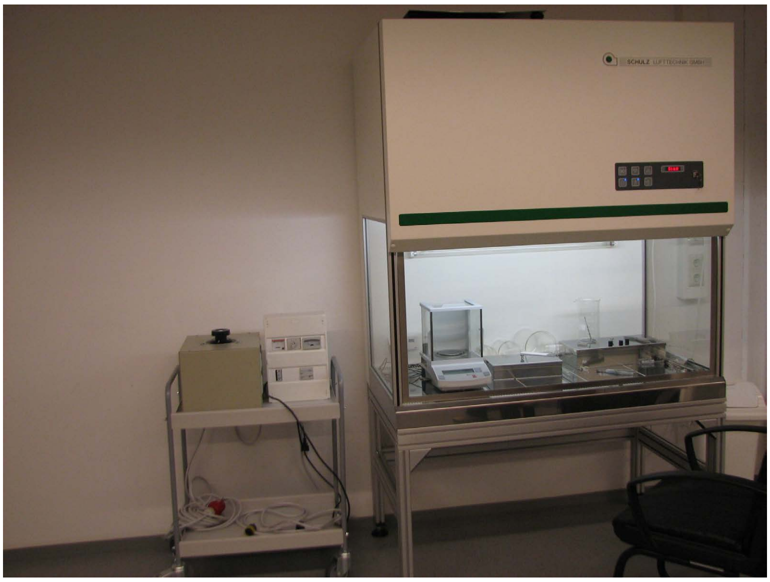


Figure 5. Laminar cabinet.

conditions of a laboratory atmosphere using the analytical balance Mettler Toledo with readability 0.1 mg.

3. Results and Discussion

The results of the mass gain measurements of the $Ca_{0.33}Li_{0.48}Mg_{0.19}$ ternary alloy is shown in Figure 6, where m_0 is the initial sample weight found under glove box conditions, $\Delta m(t)$ is the mass gain during time t of exposition to air, and the ratio $\Delta m(t)/m_0$ is the measure of the current specific sorption capacity. It can be seen from the graph that, under normal conditions, the specific sorption capacity of this alloy by the end of the measurements reaches a value of about 2 g of atmospheric gases per 1 g of the alloy.

Visual evidence of what happens in this case with the alloy under study is provided by Figure 7 and **Appendix 1**, which show the decay of two samples weighing 0.032 g each. Taking photos of this dynamic picture of the corrosion destruction of the alloy in air was carried out synchronously with the procedure of weight measurements. However, some photos shown in Figure 7 are enough to see how the decomposition feeds the chemical reaction of the gas with the alloy, exposing new areas of the metal surface.

Sorption curves $\Delta m(t)/m_0$ of the intermetallic compound $CaLi_2$ are shown in Figure 8.

In this case, the specific sorption capacity is about 1.75 g of gases per 1 g of alloy. Both of these results, the sorption capacity of the ternary alloy and the binary one, equal to 2 g/g and 1.75 g/g, respectively, should be attributed to the chemical capture of O_2, CO_2 and H_2O, *i.e.*, those constituents of air with which Ca, Li and Mg are capable of reacting at T_{room}. Chemical analysis of the final product shows that the powder mass contains oxides, hydroxides and carbonates of metals with a clear predominance of hydroxides and carbonates. Numerical

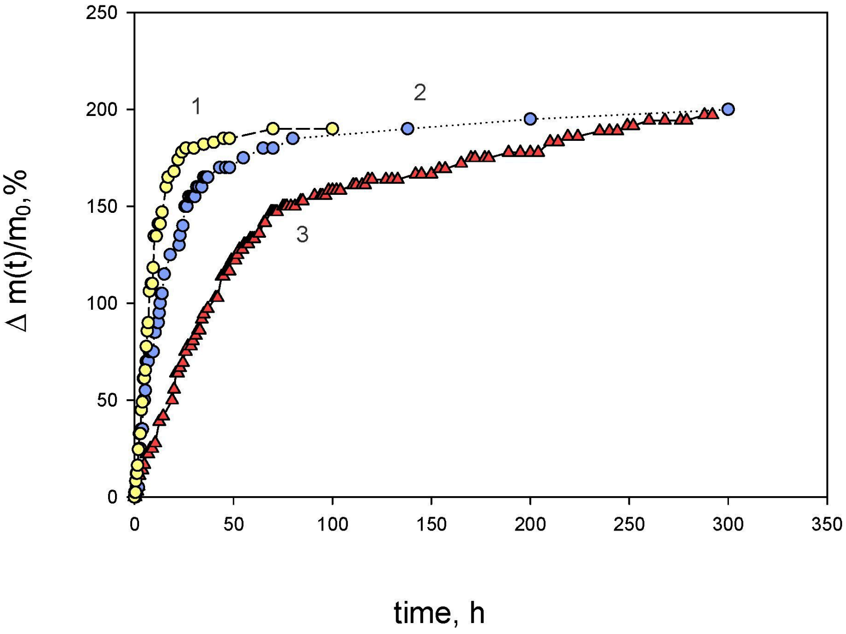
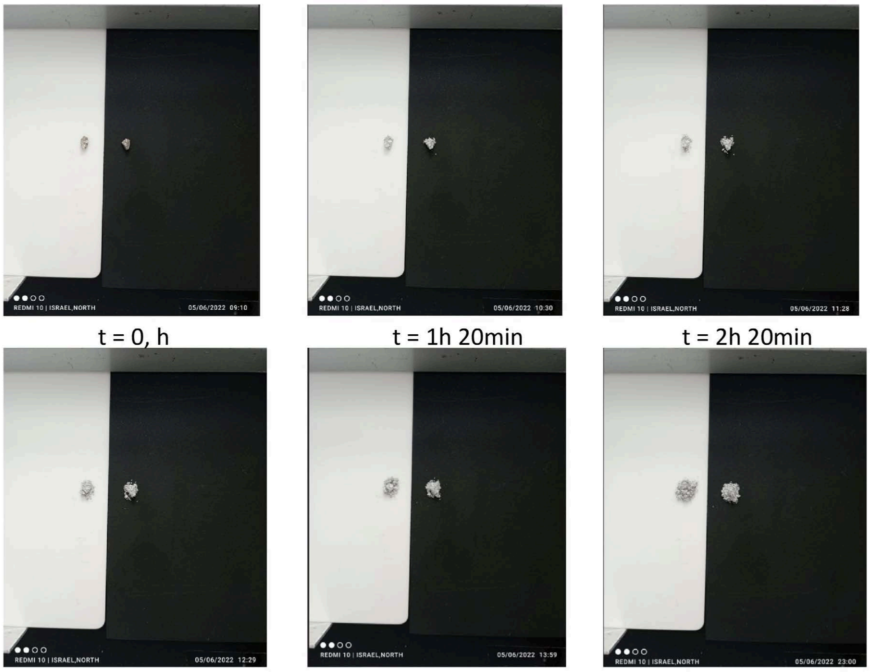


Figure 6. Sorption curves $\Delta m(t)/m_0$ of the intermetallic phase $Ca_{0.33}Li_{0.48}Mg_{0.19}$. Curve 1 (sample: 23 particles with a total mass m_0 = 0.024 g), curve 2 (sample: 4 particles with a total mass m_0 = 0.025 g), curve 3 (sample: one particle with a mass m_0 = 0.036 g).



t = 0, h

t = 1h 20min

t = 2h 20min

t = 3h 20min

t = 4h 50min

t = 13h 50min

Figure 7. Decomposition of the $Ca_{0.33}Li_{0.48}Mg_{0.19}$ ternary alloy in air at room temperature. White substrate—alumina plate; dark substrate—carbon plate.

estimates of the specific sorption capacity performed for the ternary and binary alloys under the assumption that there is no free metal in the products give 2.05 g/g and 1.8 g/g, respectively.

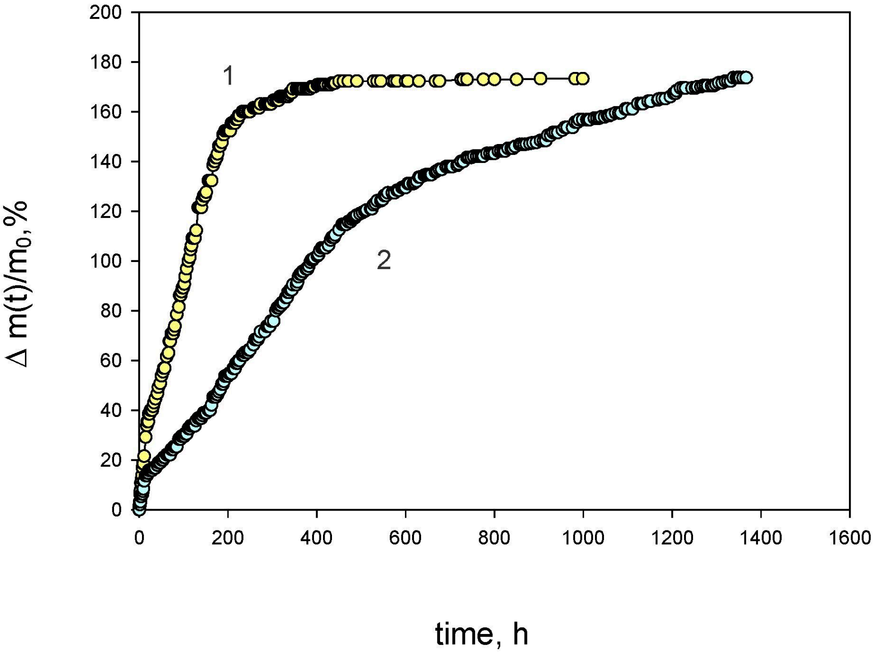


Figure 8. Sorption curves $\Delta m(t)/m_0$ of the intermetallic phase $CaLi_2$. Curve 1 (sample: 5 particles with a total mass $m_0 = 0.07$ g), curve 2 (sample: one particle with a mass $m_0 = 0.1$ g).

The experimental curves $\Delta m(t)/m_0$ presented in **Figure 6** and **Figure 8** contain information about both the specific sorption capacity of the alloys and the rate of the sorption process. Both groups of alloys behave in a similar way: at first, their sorption curves diverge, and then they gradually converge and finally reach the limit level of sorption capacity. As follows from the analysis of the obtained data, this level is determined by the stoichiometry of the reaction products in the gas/metal system.

The second characteristic of the process, the gas sorption rate, measured by the slope of the curve $\Delta m(t)/m_0$ to the t axis, depends on the composition and production history of the alloy, for example, on its specific surface area. The influence of this value on the sorption kinetics is shown in **Figure 9**, which is the initial part of **Figure 6**. It can be seen that for samples with a more developed starting surface, the rate of gas capturing is higher.

While the correlation between the sorption kinetics and the value of the surface area of the sorbent is quite understandable, the observed overall steepness of the sorption curves $\Delta m(t)/m_0$ was a surprise. Indeed, in this case, the high sorption rate is by no means a consequence of any significant technological efforts, but a natural response of the reactive intermetallic phase to such an action as bringing it into contact with a gaseous medium, while this phase itself is the macroparticles of the alloy with a monolithic structure. Here, the response is understood as the rapid decay of the sample (see **Figure 7**).

Previously, similar alloys have already been studied by the dynamic sorption method, but on powder samples ranging in size from 40 to 250 micron [17] [18].

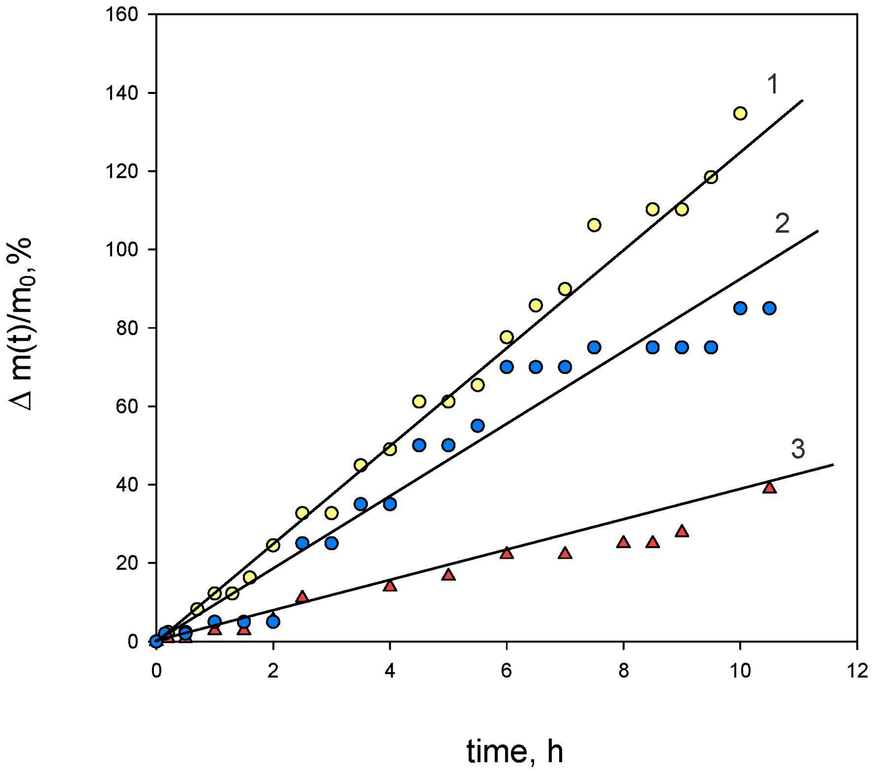


Figure 9. Detailed view of the starting section of the sorption curves $\Delta m(t)/m_0$ shown above in **Figure 6**.

At a gas pressure above the samples of about 10^{-4} mbar, the sorption speed, depending on the composition of the alloy and the nature of the test gas, is from 1 to 11 L/s, being not inferior in this respect to the best known sorbing materials. Elementary calculations show that the data of **Figure 9** fit into the frames obtained in [17] [18].

Thus, according to the measurements, the cast samples of the $CaLi_2$ and $Ca_{0.33}Li_{0.48}Mg_{0.19}$ alloys, being an easy-to-manufacture material and possessing a high rate of sorbing atmospheric gases, at the same time reached the theoretical limit of the sorption capacity, surpassing in this respect the getters of the new generation called inks by an order of magnitude. Here we mean products from the Hermetic Solution Group of the HGI series [19], from SAES Getters of the AqvaDry series [6], from MacDermid Alpha of the STAYDRY series [20], etc.

If, in addition to O_2, CO_2 and H_2O, other gases such as N_2 and/or H_2, are to be removed, it is sufficient to include Sr or Ba among the components of the intermetallic compound. For example, according to experimental data [3] the specific sorption capacity of intermetallic compound Li_3Sr_2 is quite high, reaching 1.5 g/g in air. The fact that the Li_3Sr_2 phase is somewhat inferior in sorption capacity to the $CaLi_2$ and $Ca_{0.33}Li_{0.48}Mg_{0.19}$ intermetallic compounds just indicates the capture of large amounts of nitrogen by strontium, the molecular mass of which is lower than that of O_2, CO_2 and H_2O.

The problems associated with the sorption selectivity of IIA metals are insignificant and can be solved by selecting the necessary components of the reactive alloy, however, such experiments helped to draw attention to another, more important circumstance. The sorption capacity of the reactive alloy and the sorption capacity of its constituent components in an active gas atmosphere sooner or later reach the same value. However, the time of such an event, when these values approach each other, depends on the phase composition of the alloy. As experience shows, the time it takes for the sorption capacity to reach the limit value is minimal in the case of alloys that are intermetallic compounds with Li as one of the components.

Comparing the graphical data of cast samples of $CaLi_2$ phase (**Figure 8**) and the results of sorption data obtained on bulk samples of Li [13] and Ca [21], one can see that the reaction of gas and free metal, when it has a monolithic structure, refers to the slowly running processes. The reason for this should be sought in the high plastic properties of pure metals; it is this plasticity that is responsible for their low sorption kinetics, which is completely determined by the loose layer of the products that slowly grows on the surface of the metal.

A confirmation of this can be found in [13]: from the photographs presented in this work, it can be seen that the lithium sample, when exposed to air, increases in size with time, as if swelling and remaining geometrically similar to itself, while maintaining overall integrity. These observations support the idea of replacing IIA metals and/or lithium, when they are used as sorbent materials, with their own alloys, but in the form of a brittle phase, *i.e.* with intermetallic phases. Thus, based on the above data, we can conclude that intermetallic phases based on IIA metals are the best sorbing material today. Their sorption capacity is an order of magnitude higher than that of inks-type getters, while IIA metals and lithium, having the same sorption capacity as intermetallic compounds, lose to these phases by a factor of tens in terms of sorption kinetics (indeed, while the Li_3Sr_2 phase [3], the ternary alloy $Ca_{0.33}Li_{0.48}Mg_{0.19}$ (**Figure 6**) and the compound $CaLi_2$ (**Figure 8**) have time to react with air gases on average about a day, their components require several weeks for this [13] [21]).

3.1. Sorption Mechanism and Sorption Pause

Let us consider the question of the temporary stability of reactive alloys to air, this important characteristic for production, as was mentioned in the introductory part of the paper. Note that the curves $\Delta m(t)/m_0$ of intermetallic macroparticles with a monolithic structure (**Figure 9** and **Figure 10**) clearly differ from the sigmoid yield curves of the heterophase gas/metal reaction [22]. While a characteristic feature of the sigmoid curves describing powder materials is the incubation horizontal line segment at the initial stage of the process, the curves on **Figure 9** and **Figure 10** consist of a whole chain of such segments, successively rising above the t axis. In essence, these curves are nothing more than a graphic image of the picture of the decay of the ingot, which is given in **Figure 7**. The stepped structure of these graphs also serves as a dividing line between them

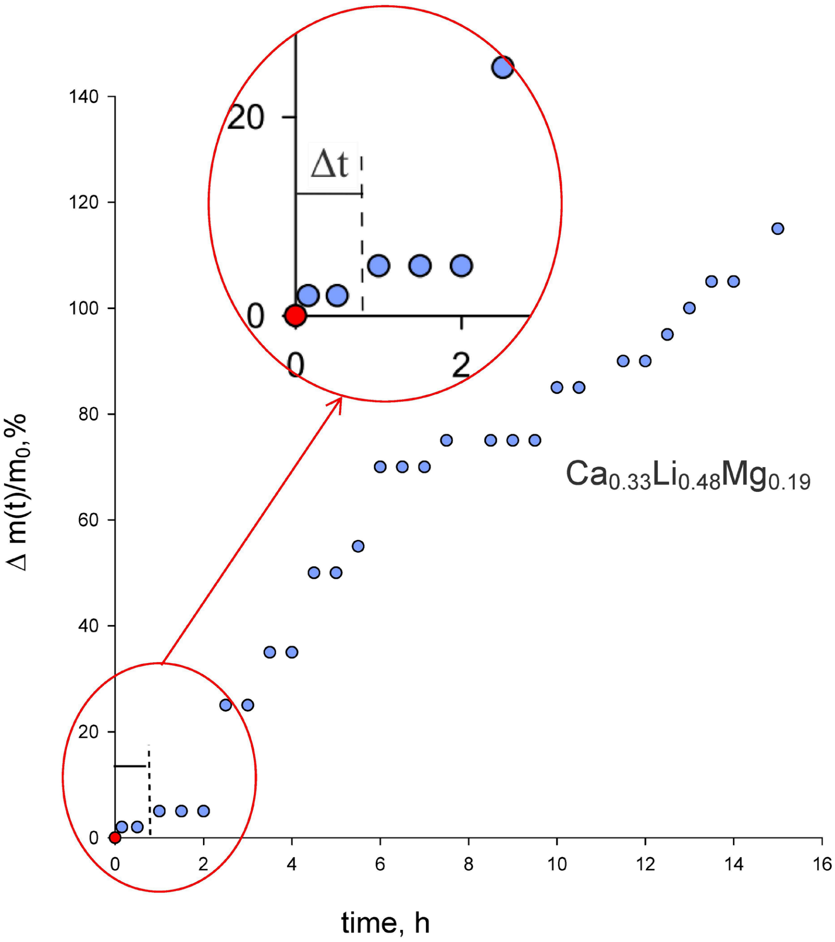


Figure 10. Influence of corrosion on the form of curves $\Delta m(t)/m_0$ of intermetallic reactive macroparticles. Experimental data of phase $Ca_{0.33}Li_{0.48}Mg_{0.19}$ (curve 2 from **Figure 6**); interval Δt corresponds to the sorption pause.

and the monotonic sorption curve $\Delta m(t)/m_0$ obtained by the authors of [13] in the study of bulk lithium.

Figure 10 contains data on the first 16 hours of exposure to air for four pieces of $Ca_{0.33}Li_{0.48}Mg_{0.19}$ alloy of total mass 0.025 g (curve 2 on **Figure 6**). The blue dots on the sorption curve $\Delta m(t)/m_0$ refer to weight measurements in air, the red dot—in a glove box under argon. The red dot is followed by the first two blue dots obtained by weighing the sample in air 9 and 30 minutes, respectively, after it was taken out of the glove box. Both are on the same level, exceeding the initial weight by 2%. The next three points, the last of which corresponds to the time $t = 2$ h, also give the same weight gain equal to 5%, then the graph grows by two more points, at a level of 25% gain, and so on.

Let us look at the behavior of reactive alloys in a gaseous medium from the point of view of [3], drawing a parallel with the sorption behavior of adsorbents. Simplifying the problem, let us represent the specific sorption capacity of the adsorbent in the saturation state as product $kS\Delta h/m_0$, where S is the available for gases specific surface area, Δh is the thickness of the layer with gases on the surface, m_0 is the initial mass of the adsorbent, and k is the proportionality coefficient.

In contrast to adsorbents with their highly porous structure and constant S, getters reactants are bodies with a monolithic structure and initially low value of surface S_r, which abruptly increases in a gaseous medium after each fracture event by $2s_i$, where s_i is the surface area of the i-th fracture. Further, while the S value of adsorbents is limited by the requirement of mechanical strength, getters reactants are initially targeted for decomposition and are capable of surpassing any adsorbents in terms of the surface area in the course of their corrosion decay.

As for the Δh layer, for adsorbents, it is formed as a dense film with a thickness of one to several atomic layers, which isolates the metal from gases and completely stops the interaction between them, while reactive alloys refer to the case when Pilling-Bedworth Ratio < 1 [23] with all the ensuing consequences. In this context, it is important that, at the interface gas/metal, the defective layer of products $\Delta h(t)$ grows continuously; initially it grows rapidly, but as it thickens, its growth rate slows down. And when, finally, its thickness grows to the micron level Δh_r the linear growth stabilizes with a very small slope of the sorption curve $\Delta m(t)/m_0$ to the t axis, which indicates the beginning of the incubation stage of the sorption process [3].

The peculiarity of the interaction of gas with the reactive alloy with a monolithic structure is that here the incubation phenomena manifest themselves throughout the entire sorption process until the alloy completely disintegrates. Indeed, the horizontal line segment Δt of the sorption curve (**Figure 10**), which is called the sorption pause [3] and which appears when the cover layer reaches the thickness Δh_r, is only the first of many incubation steps of this curve. It is followed by a jump to the next step, which is higher, and then another and another, where each of these steps is the successive incubation stage in the development of the general sorption process.

In the first approximation, each jump leads to a mass gain of $2ks_i\Delta h_r$, where k is close to the analogous coefficient for adsorbents, but the thickness of the layer Δh_r exceeds Δh of adsorbents by hundreds and thousands of times. Therefore, long before the S_r of getters reactants approaches the S of the adsorbents, the sorption capacity of the former will already exceed the sorption capacity of the latter.

It follows from the stepwise shape of the sorption curve that the sorption kinetics of intermetallic phases is determined by the length of the incubation steps, and that this kinetics can be controlled by influencing the intensity of the corrosion processes in the bulk of the alloy. However, excessive acceleration of the sorption can lead to a conflict of interest if the length of the sorption pause Δt (**Figure 10**) turns out to be small and intensive decomposition of the alloy begins before the end of the procedure of transferring the getter inside the target shell.

In the applications of getters reactants, the sorption pause is assigned the status of a sacrifice, so it is desirable to know its parameters, the height of the layer Δh_r and its length of the sorption pause Δt. Let us try to find the order of these quantities, based on the accumulated experimental data.

The thickness Δh_r of the layer of products on the surface of reactive alloys was estimated earlier using the data obtained by the dynamic sorption method [17] [24] [25] as applied to barium alloys. According to the calculations, the values of Δh_r are in the range from 4 to 7 microns. These data make it possible to determine the relative losses of the sorbent if its size is known [2]. For example, for a getter in the form of a plate with a thickness of ~1 mm such losses do not exceed 1% of the initial mass, while the value of Δt for the mentioned barium alloys is about 0.5 h.

Results close to those indicated are also obtained with weight measurements. Thus, in [3], the thickness of the cover layer at the first incubation step of the $Ca_{0.35}Li_{0.45}Mg_{0.20}$ alloy is about 4 microns, which corresponds to a loss of ~0.5% of its sorption capacity, while its sorption pause is about 3.5 h. **Figure 10** gives somewhat different data: the sorption pause in this case is $\Delta t \approx 1.0$ h, and the loss of sorption capacity is about 2%. Further, the work [3] also gives information about the sorption pauses of the intermetallic phases $CaMg_2$ with $\Delta t \approx 1.0$ h and its derivative phase $Ca_{0.35}Li_{0.10}$ $Mg_{0.55}$ with $\Delta t \approx 0.5$ h.

Although the given examples are chaotic, they show that the values of the sorption pause Δt for alloys of Li with IIA metals are large enough to carry out the installation of the getter reactant in the working position in air. This conclusion is all the more true since the length of the sorption pause and the level of its elevation above the t axis are adjustable values that can be adjusted to the user's interests by appropriate processing of the alloy. As a first step, such an adjustment can be realized by changing the value of the specific surface area of the getter reactant (see **Figure 9**).

More radical solutions are based on the mobilization of the process of solidification and mechanical processing of the ingot to create in it that level of residual stresses and that concentration of defects that can lead to the appearance of an alloy with the sorption curve of the desired form. Let us remind that all these discussions of the stepped structure of sorption curves and the sorption pause make sense only in the cases when we are talking about reactive intermetallic phases in a form of monolithic bodies.

3.2. Porous Partition for Getter Housing

The real problem for vacuum devices containing getters is the formation of free solid particles during the sorption process [17]. The number of such particles is negligibly small in the case of adsorbents, but catastrophically large when using getters reactants. Therefore, where it is necessary to capture really large amounts of gas, there is only one thing left—to build a gas-permeable porous wall that will separate the getter from its neighbors inside the shell.

Depending on the design of the vacuum gap, such a dividing wall can be any porous material that is permeable to gases, but retains solid particles. Let us consider in the most general form the solution of such a problem on the example of vacuum insulating glass (VIG) (**Figure 11**).

With regard to the given product, from the very beginning in the late 90s, when interest in it was revived [26] [27], a single structural concept of the VIG was established. This VIG (**Figure 11(a)**) is created by a hermetic seal 1 connecting two glass panels 2 and 5 at their periphery with sealing materials such as metal eutectic, glass frit, resin, etc., which isolate the vacuum gap 3 from the outside environment. Getter 6, which acts as a chemical pump that captures gases, is located inside gap 3. However, the desired result, which was announced as a reliable thermal insulation of such VIGs for many decades, was not achieved.

The reasons for the failures are known—they are the low sorption capacity of adsorbents and the difficulty of placing them inside the VIG in the right amount. **Figure 11(b)** schematically shows an alternative approach based on getters

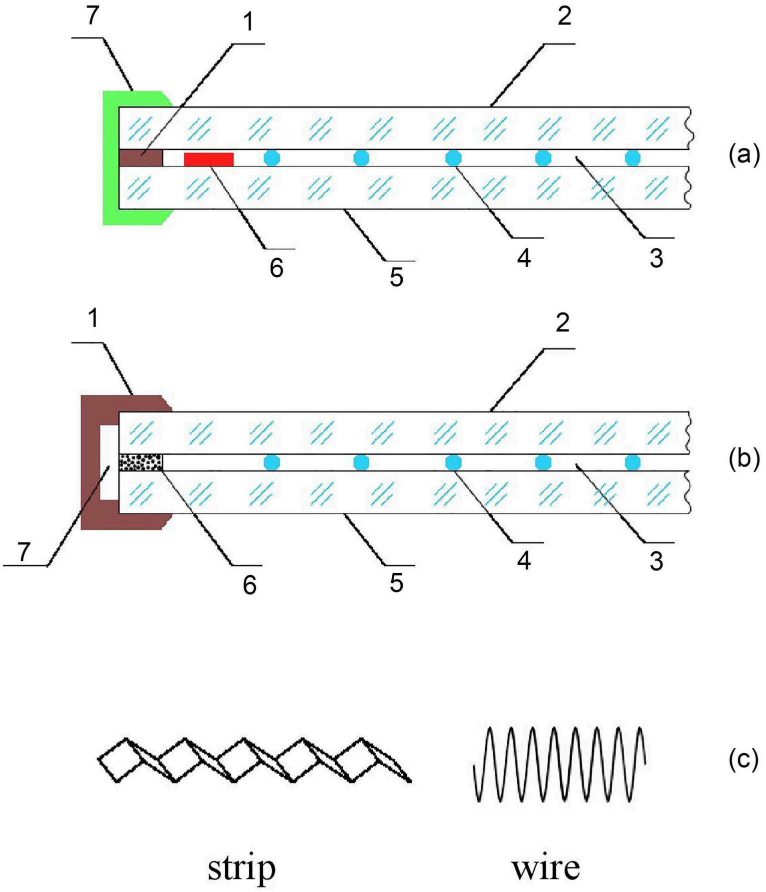


Figure 11. Vacuum insulating glass. (a) conventional VIG model: 1—seal material; 2—glass panel; 3—vacuum gap; 4—pillar; 5—glass panel; 6—getter; 7—frame; (b) a new VIG model: 1—a frame made of dense material, hermetically connected to panels 2 and 5; 3—vacuum gap; 4—pillar; 6—porous partition; 7—getter housing; (c) two types of getter material: extended strip and wire, which in the form shown are ideal for filling the getter housing 7 around the entire perimeter of the VIG.

reactants and at this providing a way to avoid contamination of gap 3 with solid products of decay. This is a complete rejection of the stereotype in the form of edge seal 1 (**Figure 11(a)**) and the replacement of the edge seal with porous partition 6 (**Figure 11(b)**). Another innovation is the replacement of the decorative frame 7 (**Figure 11(a)**) with a two-functional frame 1 (**Figure 11(b)**), which insulates vacuum gap 3 from the environment and at the same time with the help of partition 6 forms outside gap 3 area 7 as a getter housing.

Figure 11(c) shows ribbon and wire samples of getters reactants, which encircle the VIG along the entire perimeter, being inside the getter housing 7 (**Figure 11(b)**), which radically improves the conditions for evacuating gases from the vacuum gap. The permeability of the porous partition 6 along the perimeter of the entire VIG is quite high, and the amount of the getter mass can be increased many times compared to the existing solution (**Figure 11(a)**). There are several options for assembling the VIG according to **Figure 11(b)**, and it is this design that is likely to become the direction of vacuum glazing, which will turn the ability of vacuum insulating glass to maintain thermal insulation for hundreds of years, not just decades, into a common standard.

In this paper, we do not discuss the ways to remove air from gap 3 (**Figure 11**), which can be done with or without an external pump.

This is planned to be considered in a future publication, which will also describe other applications of getters reactants, including their use in MEMS, Vacuum Traps, in the production of double metal walls with a vacuum gap for thermal insulation, etc.

4. Conclusions

1) The results of this work confirm the empirical sorption model, according to which the interaction of gases and lithium alloys with IIA metals is the integration of two processes: the continuous growth of a loose layer of products on the alloy surface and the corrosion decomposition of the mentioned alloys with the participation of mechanical forces. Such a sorption mechanism opens up new possibilities in the field of vacuum technologies.

2) The gas sorption rate of reactive alloys is determined by the kinetics of their corrosion decay, which is set at the stage of alloy production by selecting its composition. According to new data, the leaders in terms of decay kinetics and hence in terms of sorption rate as well are intermetallic phases formed in binary, ternary, or multicomponent systems lithium IIA metal. This behavior of intermetallic phases is explained by their high brittleness and low mechanical strength.

3) The considered intermetallic phases reach in a gas medium an extremely high specific sorption capacity, which corresponds to the stoichiometry of the reaction products of these phases with gases. Together, these extremely high sorption capacities and maximum sorption kinetics give intermetallic phases a decisive advantage when applied to sealed vacuum devices.

4) The replacement of traditional highly porous or dispersed sorbing materials with intermetallic phases in the form of microbodies with a monolithic structure results in a whole range of additional technological and economic benefits. Let us point out here the rejection of thermal activation, which is not needed due to the special sorption mechanism of getters reactants, the presence of a temporary stability of these phases to the ordinary atmosphere, which simplifies the process of assembling vacuum products, extremely low costs in the manufacture of the getter material itself, etc.

5) The new concept of a VIG has every chance of practical success due to the following reasons: high sorption kinetics of getters reactants and their tenfold superiority in terms of specific sorption capacity over the best existing sorbents; no need for thermal activation for getters reactants; the introduction of a new structural element in the form of a getter housing, which encircles the entire VIG along the perimeter being separated from the vacuum gap by a porous partition.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

Appendix 1

Corrosion decay of the $Ca_{0.33}Li_{0.48}Mg_{0.19}$ alloy in air was carried out synchronously with the procedure of weight measurements. The link to the video file is given below: https://youtu.be/2a7mQ_i_MSY.