IOP Conf. Series: Materials Science and Engineering **387** (2018) 012037 doi:10.1088/1757-899X/387/1/012037

Influence of the technological development on the adhesion increment of metallic thin film coatings to ceramic substrates of aluminum oxide

L L Kolesnik, Myo Kyaw Hlaing and Zaw Phyo Aung

Bauman Moscow State Technical University

E-mail: kolesnik@bmstu.ru

Abstract. In this journal are considered that the comparing of the adhesion strength with and without Ti layer between substrate and current layers. Comparing of the DC magnetron and pulse magnetron with various pressure in vacuum chamber. With Ti sub layer adhesion strength 10 times more than without adhesion layers. The best value of adhesion strength was obtained by using with a direct current magnetron and pressure in the chamber 8.8×10^{-2} mbar. A series of experiments was conducted with differences substrate position and maximum and minimum distance between substrate and target to prevent the destruction of the substrate when coating with a hot cathode target, it is necessary to limit the thermal effect on it.

1. Introduction

Power electronic modules producing by the domestic industry are contained in the structure of metal-ceramic compound elements. These compounds are required for adhesion strength, sustainability to temperature changes. Typical applications: aircraft navigation systems, elements of the commutations board and etc. A typical module of power devices shown in figure 1 and consists of a commutations board on which conductive paths are formed, electronic components and cooling radiators are installed.

Literature analysis requires the necessary parameters to the power modules, the main important are the working temperature and the adhesion of the films to the substrate. During the exploitation of power modules, they are exposed to thermal and mechanical stresses, including vibration. This leads to the destruction of components from overheating and mechanical damage. Often damages occur in the substrate-conductive coating structure. So we need to choose the substrate material for removing the heat and preventing the damage which was describes above.

At the moment, these connections are performed on the basic of thick film technology, especially uses direct bonded copper DBC-technology and other various atmospheric methods. These modules are used in the field of technology associated with the need to transmit high-current signals. Thin films technology ensures generally the absence of the several types of thick film technologies and on the other indicator surpasses them. Transition to thin film technology for creating the basis soldering elements of vacuum devices and power modules will be reduced the percentages of rejects and will be improved the quality of these connections.

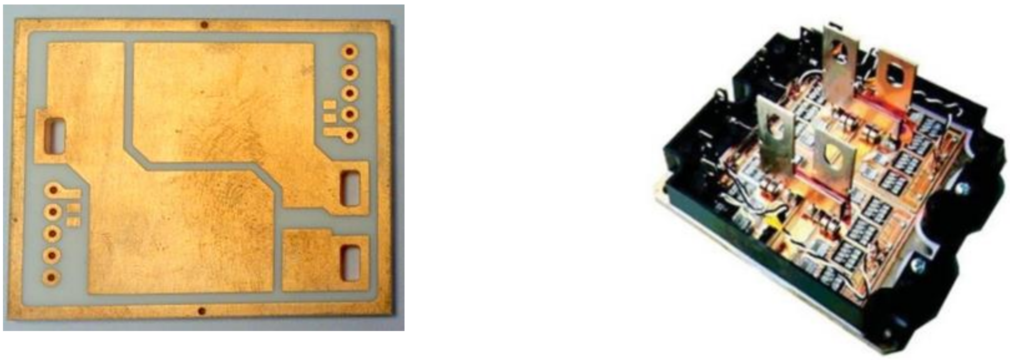

Figure 1. Typical commutation board and view of the power electronics module.

Since 2016 at Bauman Moscow State Technological University has been taken modernization of laboratory apparatus for processing thin film coating technology into vacuum. As a result, the installation was received two independent sources: thermal evaporator and magnetron spraying system. The modernization process consisted of the mounting of gas and magnetron spraying system, which provided the technology base for processing the development of thin film coating. This makes it possible to form multilayers film coatings in a single vacuum.

Special flange was designed and manufactured for apparatus of magnetron system. Cooling water continuously supplied to magnetron system along a close circuit and we have been used that cooling system for prevention of overheating and its demagnetization. However, the cooling system is realized so that was cooled magnets, but the target of magnetron by itself was not cooled and the process was heated temperature about 900 °C.

At present, various types of ceramics are used as substrate materials for the fabrication of the circuit board of power modules. In the following table show the properties of the basic materials for substrate selection. Important characteristics are mechanical strength, thermal conductivity and coefficient of thermal expansion. The coefficient of thermal expansion should be close to the film coating in order to avoid the destruction of the metal-ceramic structure when the temperature changes. Substrate of aluminum nitride is the most promising candidate for improving heat dissipation and has high thermal conductivity 10 times higher than aluminum oxide (Al_2O_3), thermal expansion coefficient close to the coefficient of thermal expansion of silicon, good mechanical properties and non-toxicity, environmentally friendly and relatively inexpensive specific durability is 5–7 times lower than the specific stability of ceramics from beryllium oxide). In terms of these important characteristics, the preferred material is aluminum nitride. However, it shows much worse adhesion performance compared to aluminum oxide.

The purpose of this work is to determine the temperature dependence of the substrate position in the chamber and the angle of spraying with magnetron sputtering. Increasing the adhesion strength of ceramic substrates for the manufacture of power electronics devices and electro vacuum devices.

2. Experimental details

A series of experiments was conducted to investigate the application of coatings in a laboratory installation. In this paper, alumina substrates are used. We chose Ti material for the adhesive layer from many popular materials, for example, Cr, Ta and Al and. etc. The adhesive layer was applied using the method of magnetron sputtering of direct current and in the pulsed mode. The coating of current films was preliminarily coated by the impulse magnetron sputtering with different frequencies and filling coefficients. The copper layer was formed by thermal evaporation, a power mode of 0.20 kV was determined for each experiment. In these regimes, a series of experiments was performed to apply multilayer $Cu/Ti/Al_2O_3$ films by two methods in a single vacuum cycle. Before coating, the substrate surface was cleaned in the ultrasonic bath for about 10 minutes, and the temperature was 25–27 °C. With ultrasonic cleaning, large grease dirt is removed due to intense local mixing under the action of shock waves created in the solvent. The disadvantage of chemical surface preparation is also the fact that this treatment does not in principle ensure the removal of physically adsorbed moisture, the more chemisorbed. Multilayer film on ceramic substrate was coated with the following conditions: Argon gas – 30 sccm; Voltages – 650 V; Coating time – 5 min; Distance – 75 mm; Power – 380 W.

3. Results and discussion

First sires of experiment is single layer current film coating on aluminum oxide substrate and then multilayer was coated on the same substrates for comparing these two films for adhesion strength. The obtained samples were investigated for adhesion strength by peel test method.

Adhesion strength with Ti layers was 10 times greater than the single-layer copper coating. It was shown that Ti inserting as adhesion layer which are used for soldering components (copper, tin-gold etc.).

To determine the influence of the application regimes of the adhesive sub layer, studies were carried out under various conditions of the power source and pressure during application. For the Ti sub layer with DC magnetron 650 V and pulse mode magnetron was chosen.

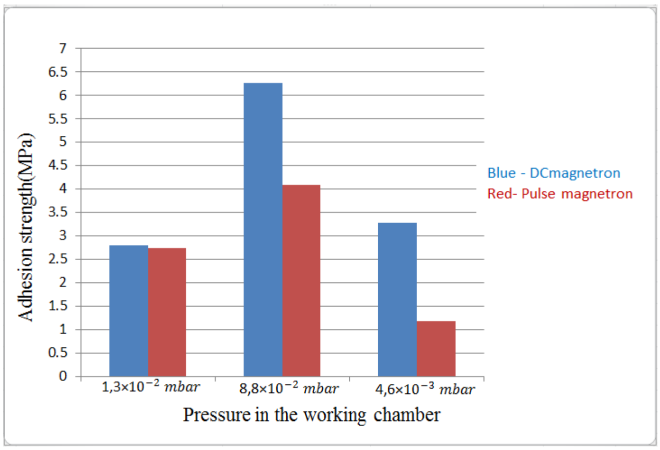

Figure 2. Comparing the adhesion strength with DC magnetron and pulse magnetron various pressures in working chamber.

The best value of adhesion strength was obtained by using with a direct current magnetron and pressure in the chamber 8.8×10^{-2} mbar.

A series of experiments was conducted to study the deposition of coatings with the temperature regime. Different frequencies and coefficient filling with pulse magnetron sputtering f -30 kHz D- 50%, f -30 kHz D -70%, f -90kHz D-70 and f-70kHz D-55 was chosen. The magnetron operated in the following mode: power - 380 W, Working gas-Argon 30 sccm, Target - titanium. The distance from the target to the substrate is 75 mm. The substrate temperature was measured with a thermocouple for every 20 seconds. At a frequency of 20 kHz and a fill factor of 80 %, the highest substrate temperature is obtained. It is determined that the substrate is heated to a temperature of 220 °C or higher, and at the initial stage the heating rate reaches up to 40 °C/min.

During the processing of regimes, cases of specimen destruction were observed. Since the deposited material comes from a hot Ti target heated to 1000℃, it has been suggested that the destruction is due to thermal effects. It was found that due to the diffuse scattering of the material, due to the high pressure in the deposition area, the back side of the substrate is dusted. High heating rate at the initial stage, leads to the destruction of films coatings. The substrate temperature was measured for different positions of the substrate holder. The maximum distance from the target to the substrate was 110 mm, and the minimum distance between them was 75 mm.

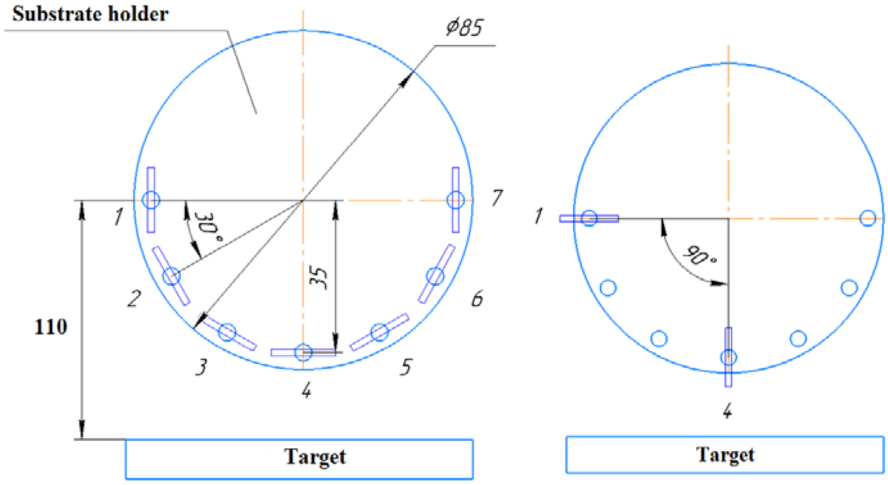

Figure 3. The location of the substrate with different angles and the distance from the target to the substrate.

In these experiments, a full factorial experiment was performed at positions 1 and 4. Two experiments were carried out, each with 3 parallel observations for each combination of factors in order to improve the accuracy of the experiment. In the experiment, the distance between the substrate and the target varies, for each distance value the spraying angle is varied. The output parameter is the temperature of the substrate. Deposition regimes describe the following.

The substrate temperature are (d=110mm, α=180˚is 75 Degree Celsius), (d=75mm, α=180˚is 93 Degree Celsius), (d=75mm, α=90˚is 109 Degree Celsius) and (d=110mm, α=90˚is 153 Degree Celsius).

It is necessary to build a mathematical model that connects the parameters of the heat flux, which will allow to determine the optimum position of the substrate to achieve the required film growth rate with minimal thermal impact.

4. Conclusion

The insertion of an adhesive titanium sub layer leads to an increase in the adhesive strength of a copper film on an alumina substrate by nine or more times.

The best adhesion strength is achieved when the adhesive under layer of titanium is applied by DC magnetron at pressure of 8.8×10^{-2}mbar.

To prevent the destruction of the substrate when coating with a hot cathode target, it is necessary to limit the thermal effect on it.

The magnitude of the thermal impact is determined by the geometric characteristics of the equipment (distance) and the technological parameters of the process (temperature, pressure, evaporation rate

The developed mathematical model will allow to determine the optimum position of the substrate during the deposition from the hot cathode to ensure the required minimum thermal effect on the substrate.

References

[1] Kolesnik L L, Zhuleva T S, Predtechenskiy P O, Myo Kyaw Hlaing and Zaw Phyo Aung *Journal of Physics: Conference Series* **872**

IOP Conf. Series: Materials Science and Engineering **387** (2018) 012037 doi:10.1088/1757-899X/387/1/012037

[2] *Handbook of deposition technologies for films and coatings: science, applications and technology* ed. P. M. Martin (Burlington; Oxford: William Andrew/Elsevier) 2010 912
[3] Luchkin A G and Luchkin G S *Cleaning substrate surfaces for coating deposition by plasma methods in vacuum*
[4] Kolesnik L L, Dejev B A and Seleznev A B 2013 *Vacuum science and technology: Materials of the 20th scientific and technical conference with the participation of foreign specialists* 165–7
[5] *US Patent 5571332 Electron Jet Vapor Deposition System* 1996
[6] Danilin B S and Syrchin V K 1982 *Magnetronnyye raspylitel'nyye sistemy* (Radio i svyaz') 72
[7] Marakhtanov M K 1990 *Magnetronnyye sistemy ionnogo raspyleniya (Osnovy teorii i rascheta)* (M.: BMSTU) 76