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Metallic coatings for MEMS structures

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Abstract. This paper presents the results of mechanical stresses measurement in thin metal films in the composition of MEMS structures. The main requirements for metal films for MEMS are presented, recommendations for choosing methods of film deposition are given.

1. Introduction

Thin metal films are a part of microelectromechanical and micro-optomechanical devices, switches, sensors, actuators. They are used to form conductors, contacts and reflective coatings, so as in microelectronics technology. However, their area of use in MEMS is wider. Metals are often used as structural layers, as well as sacrificial or protective layers, which are subsequently removed.

It should be noted that mechanical properties play an important role for MEMS applications, and therefore, much attention in this work has been paid to them.

2. The application of metal films in MEMS

Table 1 shows the main areas of application of metal films for micro-optomechanical structures.

Table 1. The main application of metal films in MEMS.

Main applications in MEMS	Metal films
Structural (mechanically movable, functional) layers	Au, Cr, Ni, W
Adhesive and contact sublayers	Cr, Ti, Ta, W, V
Resistive and thermoresistant films	Ni, Pt,W
Form memory	Alloy Ti-Ni
Magnetic films	Fe, Alloy Fe, Co, и Ni
Reflective coatings	Au, W, Pt, Cr, Al
Conductive coatings	Au, Ni, Al
Sacrificial layers	Al, V, Cu, W
Masks for wet and dry etching	Al, Ni, Cu, Cr

The application of metal films in MEMS can be different. The following requirements are putted on films, depending on the area of their use:

- Resistance to certain etchants;
- Absence of pores and defects;
- High reflection coefficient;

- Minimum mechanical stresses;
- Good adhesion;
- High conductivity;
- Ohmic contact to the underlying conductive layer.

Compositions of metal films are often used to solve all these problems. The properties of metal films are strongly dependent on the methods and conditions of their deposition. A wide range of deposition methods makes thin metal films one of the most versatile classes of materials used in MEMS devices.

3. Methods of deposition metal films for MEMS

There are a lot of methods of producing metal films. They differ in the temperature of deposition, the degree of vacuum and other parameters. These parameters determine the properties of the produced films. The process temperature is one of the most important parameters of the film producing for several reasons. Firstly, this is the occurrence of thermomechanical stresses. They can lead to bending of the substrate or film peeling. Furthermore, they can strongly influence on the mechanical characteristics of the MEMS device. In addition, MEMS structures are often products in which the film is freed from the substrate. And if the value of the mechanical stresses is significant or they are compressive, this leads to the bending of such structures when they are freed from the substrate and, as a consequence, structures become unsuitable for use. Secondly, MEMS structures include multilayer compositions, and at high temperatures there can be interdiffusion of the layers, which leads to a change in the properties of the films. For example, during annealing of membrane elements with a composition of gold-chromium layers, chromium diffused to the surface, which led to a change in the mechanical properties of the composition of the layers and a change in the characteristics of the device. The application of metallization, as a rule, is one of the final stages of structure producing. Methods of depositing metal films at lower temperatures such as magnetron deposition should be chosen to avoid layer interdiffusion. Also, it is possible to use barrier layers.

A low vacuum in the chamber during deposition can result in the film saturation with impurities from the residual atmosphere. This is not desirable for micromechanical structures because the impurities from the residual atmosphere can strongly change the value of the mechanical stresses of the metal film, and as a result, the mechanical characteristics of the entire structure.

In addition, since the mechanical characteristics of MEMS are controlled not only in the process of producing structures, but also in the process of modification and operation of the device, it is important that it is possible to form metal films on already finished structures (for example, to produce electrodes). The following requirements are often made for MEMS due to the features of technology and design:

- Low film deposition temperatures;
- High vacuum;
- Possibility of deposition metal on the already produced device;
- The required value of mechanical stresses.

However, not all technological processes can meet these requirements. Therefore, the choice of the method of forming metal films depends on the specific task. The required characteristics of the film are taken into account.

4. Methods for measuring the mechanical characteristics of thin films

Measurement of mechanical stress in microelectronics technology is mainly carried out by measuring the bending of the substrate under the action stresses of the film or by X-ray diffraction [1]. MEMS technology uses other methods related to the design features and the application area of the device. For example, a method of measuring the deformation of a fixed–fixed film is used. Registration of the deflection is often carried out by optical methods. In the structures obtained by the technology of bulk micromachining, methods based on forced deformation of the film under the action of external forces

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are used: pressure or electric action. These methods are considered in detail in [2]. In this work we used a technique developed for micromechanical membranes based on measuring the deflection of a membrane under the action of air pressure. The measurements were held by means of a Fabry–Perot interferometer formed by the reflective end of the optical fiber and the reflecting surface of a metallized membrane [3].

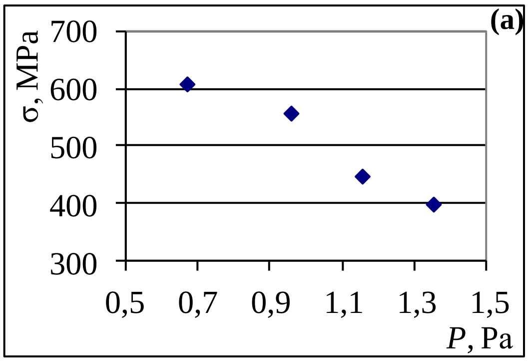
5. Results and discussion

Mechanical stresses of many metal films obtained by magnetron deposition can be both tensile and compressive depending on the process conditions [4]. The sign and magnitude of the stresses play an important role for MEMS devices. Full compensation of mechanical stresses can be achieved by using film compositions with opposite mechanical stresses. And, as a result, the sensitivity of the structure increases.

Thin films of tungsten, obtained by magnetron deposition, have compressive mechanical stresses from the measurements. Therefore, they compensate the tensile stresses. The fact that the stresses are compressive can be explained by the oxidation of the film in the first stages of deposition. Thin films of titanium, obtained by the magnetron method, also have compressive mechanical stresses. High compressive stresses often lead to their detachment from the substrate in local areas. In addition, a thin layer of titanium oxide is observed on the surface due to the ability of titanium to strongly oxidize in air. Therefore, titanium films are recommended as a sublayer, and the deposition of the base material should be carried out without depressurizing of the vacuum chamber. The compressive stresses of titanium can compensate the tensile stresses of the structural layers.

Mechanical stresses in nickel films obtained by the method of magnetron deposition, are near zero, according to the measurements.

The results of measuring mechanical stresses in thin chromium films obtained by the magnetron method in various technological regimes were obtained. The feature is the high content of chromium oxide in the used target. Mechanical stresses in chromium films of thickness 100 nm, obtained in the investigated range of temperature and pressure of the working gas, are tensile and tend to decrease during deposition with increasing pressure of the working gas in the chamber (Figure 1, a). The mechanical stresses of the resulting films also change when the substrate temperature changes during deposition. The obtained dependence is complex (figure 1(b)).



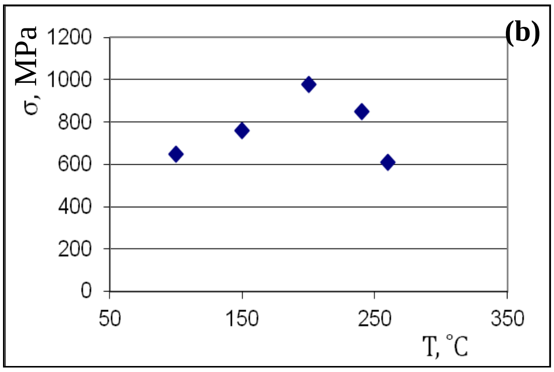


Figure 1. Dependence of mechanical stresses in chromium films on the working gas (Ar) pressure in the chamber during deposition processes by the magnetron method (**a**) Dependence of mechanical stresses in chromium films on substrate temperature during deposition processes by the magnetron method (**b**).

Table 2 presents the results of measuring mechanical stresses in various metal films deposited by magnetron method and shows how they were used in MEMS structures.

The obtained results show that not only the choice of the method, but also the choice of parameters of the deposition process have a significant effect on the mechanical properties of metal films. Layers with opposite mechanical stresses should be chosen to minimize the total stresses for MEMS compositions, which include sublayers, structural materials, and reflective or conductive coatings.

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Table 2. Results of measuring mechanical stresses in various metal films (Me), deposited by the magnetron method.

Me	Film thickness, nm	Stress sign	Mechanical stresses, MPa	Application in MEMS
Cr	100	tensile	450 – 650 (depend on the conditions of the deposition process)	Reflective coatings and structural layers for sensors
Ti	100	compressive	-200	Sublayer for reflective and conductive coatings
W	80	compressive	-150	
Ni	100	–	Near zero	Reflective coatings and conductive layers for sensors
Au	90	change sign	From -190 to 560	Reflective coatings and structural layers for sensors, electrode material of activated membrane elements, wiring and commutation layers for MEMS switches

6. Conclusions

The values of mechanical stresses in thin films of various metals used in MEMS structures for various purposes deposited by a magnetron method are obtained.

The mechanical stresses in metal films depend on the conditions and methods of their deposition. They depend not only on the difference in the temperature coefficients of linear expansion of the film and substrate. Mechanical stresses are formed as a result of oxidation processes during growth, as well as at higher temperatures due to interdiffusion of materials used as structural layers. The layers of metals used for adhesion are easily oxidized and often form compressive stresses. This is especially true for thin layers. Such metal films like Ni or Au oxidize to a lesser degree and can have mechanical stresses near zero or change the sign of mechanical stresses depending on the deposition conditions.

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