RESEARCH

Formation of SiO_2 and $CrSi_2$ thin films on silicon surface and measurement of electrophysical parameters

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ABSTRACT

In this paper, we described the formation of SiO_2 and $CrSi_2$ thin films using a magnetron sputtering device. The surface morphology of the films was analyzed using ASM and SEM devices, and the elemental composition of the samples was determined using an energy-dispersive X-ray measurement device. Electrophysical quantities were determined using the HMS-5000 measuring device. According to the measurement results, it was confirmed that $CrSi_2$ semiconductor nanofilms and SiO_2 dielectric thin films were successfully grown by solid phase ion-plasma method. The charge carrier mobilities, bulk and sheet concentrations of the thin films are consistent with the values in the available literature. These layers are of practical importance in the use of sensors operating in the IR range. The nature of interactions through distance such as gravitational interaction, electromagnetic interaction, nuclear interaction, etc.

Key words: *Magnetron sputtering device; Mobilities; Gravitational interaction; Electromagnetic interaction; Thermal phenomena*

INTRODUCTION

The metal silicides in thin films are of interest to materials scientists. Although precision synthesis methods such as Molecular Beam Epitaxy (MBE) and Pulsed Laser Deposition (PLD) provide significant control over these systems, a gap remains between ideal and realized materials. We can consider that the solid-phase ion-plasma method of the magnetron dusting device is a method that eliminates these gaps. Because thin films have different structures and chemical compositions, it is often difficult to predict which properties will occur. High-resolution structural and chemical characterization methods are needed to validate growth models, relevant theoretical calculations, and materials design. The surface morphology of the thin films was analyzed using ASM and SEM devices, the energy dispersion spectrometer was used to analyze the elemental composition, and the electrophysical parameters were measured using the HMS-5000 measuring device provided by Ecopia CORP [1-4].

The synthesis of thin films formed in a magnetron sputtering installation is carried out using SiO_2/Si and Si(111) substrates. Before forming the $CrSi_2$ film, the SiO_2/Si and Si(111) substrates were cleaned in two stages:

1. Cleaning the surface of Si(111) and SiO_2/Si (d=60 mm) substrates was carried out by washing with deionized water at a temperature of 65°C -75°C using an ammonia-peroxide mixture and drying in a centrifuge;
2. Vacuum treatment (cleaning) of the surface of the silicon wafer was carried out using an argon plasma flow onto an advanced magnetron sputtering EPOS-PVD-DESK-PRO. The plasma current is created by a cold cathode ion source with a voltage of 2.4-3.6 kV and a current of up to 134 mA for (5, 6-8, 8) minutes. During treatment, a group of diapers (1÷3) pieces is placed in a rotating device.

$CrSi_2$ films were formed on an EPOS-PVD-DESK-PRO magnetron sputtering installation at a pressure of 10^{-5} Pa and room temperature. The target purity of $CrSi_2$ was 99.6%. The diameter and thickness of the target were 76 mm and 6 mm, respectively.

Before placing the target in a magnetron machine, its composition and structure were studied using a 3D Scanning Electron Microscope (SEM) Quanta 200 from the Dutch company FEI (Figure 1).

Elemental analysis of thin films of $CrSi_2$ and SiO_2 formed in an automated and modernized magnetron sputtering installation using energy-dispersive X-ray spectroscopy, surface morphology, structure and thickness of the films were studied using an SEM electron microscope (on a standard FEI Quanta 200 F installation) and high-energy electron diffraction DBED. To measure the electrical properties, an Ecopia HMS-5000 type device was used. All $CrSi_2$ films were obtained at room temperature and were amorphous. The film was annealed at 750 K for 2 hours to obtain a polycrystalline structure.

The elemental composition of the samples was studied using energy-dispersive X-ray spectroscopy. Figure 2 shows an SEM image of an

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unheated $CrSi_2$ film. The experiment was carried out on a Quanta 200 3D microscope. Table 1 shows the percentage of elements in $CrSi_2$. As can be seen from the data presented, the sample contains the most chromium and silicon by mass and atomic percentage and very little oxygen (Figure 3).

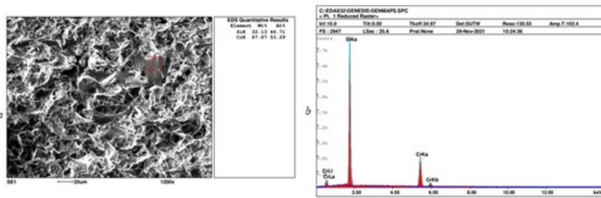

Figure 1) *Results of studying the $CrSi_2$ target using a Scanning Electron Microscope (SEM): surface image, and energy-dispersive X-ray spectrum, elemental composition of the sample*

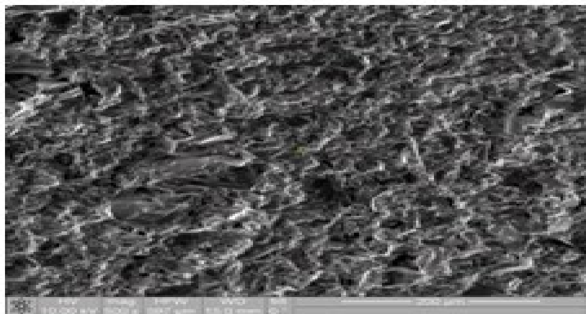

Figure 2) *SEM image of an arbitrary sample surface for elemental analysis*

TABLE 1
Energy dispersive spectrum quantitative results

Element	Element	at.%
Si, K	60, 4	62, 32
Cr, K	36, 35	33, 6
O, K	3, 25	4, 08

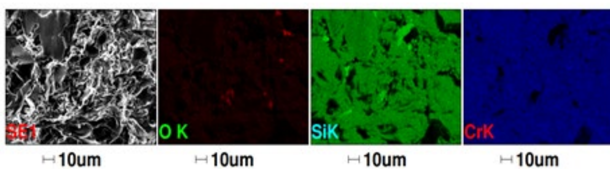

Figure 3) *Map of the elemental composition of samples*

The table shows that oxygen is present in the smallest quantity. But a film produced by magnetron sputtering cannot contain S and O atoms. So these may be environmental atoms located on the surface of the film. A fragment of the surface was taken to study the distribution of elements in depth. The selected fragment represents the surface of the sample at an angle of 54 degrees. Thanks to this, a picture of the distribution of elements along the depth of the sample was obtained (Figure 3).

The SEM image (a) and energy-dispersive spectra (b) of the surface of $CrSi_2$ films obtained by the solid-phase ion-plasma method are presented in figure 4. Films were obtained by magnetron sputtering onto the surface of a silicon substrate for 30 seconds. As can be seen from figure 4a, individual sections of the film with a size of 90 nm-150 nm (black phases) are not coated with silicone.

Analysis of the energy-dispersive spectra of the $CrSi_2$ surface (Figure 4b) shows that the concentration of Cr and Si at point 1 is about 33, 6 and 62, 32 at.%, which corresponds to the structure of $CrSi_2$. Point 2 has a very low concentration of Cr atoms. It can be seen that a certain number of $CrSi_2$ molecules are also present in uncoated Si sites. The Si(111) surface is completely covered with an amorphous $CrSi_2$ film during sputtering within 60 s (~400 Å). The SEM image and DBED pattern (inset) of a thin $CrSi_2$ film formed on a silicon surface by magnetron sputtering for 120 s and then annealed at t=477°C for 1 hour are shown in figure 5a.

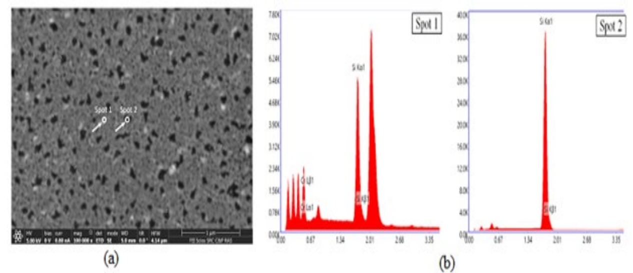

Figure 4) *SEM image (a) and energy-dispersive spectra (b) of the surface of the $CrSi_2$/Si(111) film, deposition time 30 seconds*

As can be seen from the figure, in this case a smooth and uniform polycrystalline $CrSi_2$ film is formed. Figure 5b shows an SEM image of a cross section of a thin film of the $CrSi_2$/Si(111) system. It can be seen that the film thickness is about 80 nm.

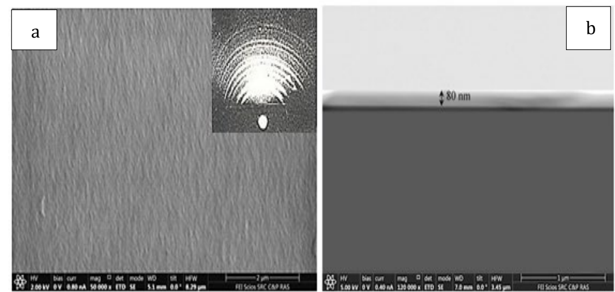

Figure 5) *a) SEM image and DBED pattern (inset) of a $CrSi_2$ thin film formed by magnetron sputtering for 120 s onto a silicon surface annealed at t = 477°C for 1 hour, b) SEM image of the cross section of a thin $CrSi_2$ film formed on a silicon surface by magnetron sputtering for 120 s and then annealed at 477°C for 1 hour*

SEM of a thin film of Silicon Oxide (SiO_2) obtained by a low-energy ion plasma method using a magnetron sputtering device, as well as the chemical composition and energy dispersive X-ray diffraction pattern of a SiO_2 sample obtained after growing oxide layers 150 nm-250 nm thick at high temperature as a substrate prepared with using an energy dispersive device. Analyzes were performed under a Quanta 200-3D microscope (Scios FEI) (Figure 6). Results (O-wt.%-34.27, at%-35.94), (Si-wt.%-65.73, at%-64.06) elements were determined in fractions.

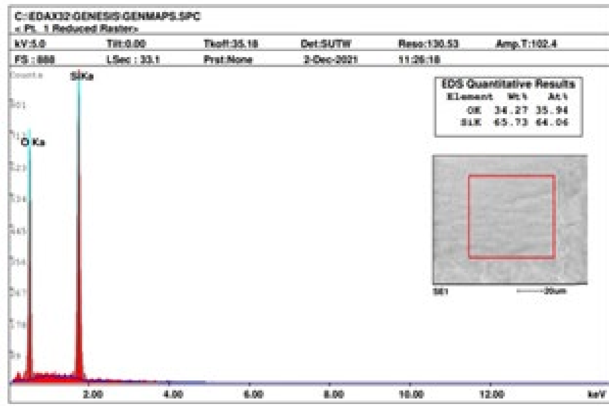

Figure 6) *Chemical composition and energy dispersive X-ray diffraction analysis of SiO_2 film*

In this section, the surface morphology and composition of SiO_2 and $CrSi_2$ films formed on the silicon surface were studied using a Quanta 200 3D Scanning Electron Microscope (SEM). $CrSi_2$/Si(111) films were formed from a $CrSi_2$ target using a modern EPOS-PVD-DESK-PRO sputtering magnetron. The composition of the resulting thin film of $CrSi_2$ silicide and the chemical bonds formed in it has been studied.

It should be noted that the Hall constant for the studied object changes with temperature within wide limits: when the temperature rises from 130 K to 300 K, it increases five times. As can be seen from Hall EMF measurements, the conductivity of the studied sample is p-type conductivity (Figure 7).

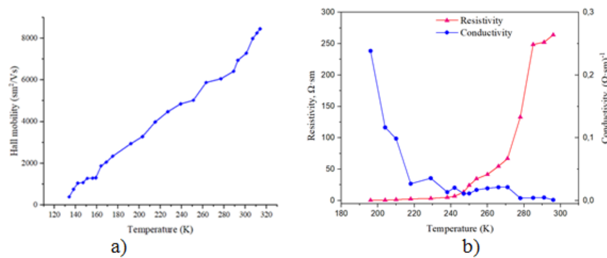

Figure 7) *a) Temperature dependence of Hall mobility of $CrSi_2$ films, b) Dependence of specific resistance and conductivity of SiO_2 thin film on temperature*

Figure 7a, 7b shows the temperature dependence of surface resistance, conductivity and specific resistance of SiO_2 thin films formed by magnetron sputtering on the silicon surface using the HMS 5000 measuring device. According to the measurement results, with the increase in temperature, the conductivity decreased, the specific resistance and surface resistance increased sharply, which can be explained by the fact that the SiO_2 film has dielectric properties.

Table 2 shows the electrophysical parameters of silicon oxide thin films produced by ion-plasma method with pure silicon and low-energy ions intended for use as a substrate.

TABLE 2
Results obtained on the HMS 5000 measuring device

Parameters	Measurement Value	Measurement result for Si substrate	Measurement results for SiO_2 thin film
Input Current	1 nA ÷ 20 mA	5 mkm	5 mkm
Bulk concentration (1/cm^3)	$10^7 \div 10^{21}$	$1{,}92\cdot10^{14} \div 9{,}02$ $4\cdot10^{15}$	$1{,}24\cdot10^{17} \div$ $7{,}16\cdot10^{15}$
Sheet concentration (1/cm^2)	$10^7 \div 10^{17}$	$11{,}437\cdot10^{14} \div$ $1{,}443\cdot10^{12}$	$1{,}33\cdot10^{15} \div$ $1{,}39\cdot10^{14}$
Mobility (cm^2/Volt·sec)	$1 \div 10^7$	984,06÷2478,3	11,143÷64,86
Magnetic Flux Density(T)	0.51 Tesla (± 0.03T)	0,53 Tesla (± 0.03T)	0,54 Tesla (± 0.02T)
Temperature (K)	80÷300	130÷300	190÷300
Measurable Sample size	5 mm × 5 mm ~ 20 mm × 20 mm size. Less than 2 mm thickness	10 mm × 10 mm	10 mm × 10 mm

$CrSi_2$ thin films grown by the solid-phase ion-plasma method were initially formed in an amorphous state on silicon and silicon oxide substrates. After thermal heating at 750 K for 1 hour, polycrystalline films were formed, as seen from the SEM and RHEED patterns. The elemental composition of the obtained films was studied, and their thickness was measured by SEM. N_e=$2.584\cdot10^{15} \pm 0.5\cdot10^{15}$ cm^{-3}, n_{sh}=$1.44\cdot10^{12} \pm 0.5\cdot10^{12}$ cm^{-2} and μ_H=31.87 ± 0.04 cm$^2\cdot$V$^{-1}\cdot$s^{-1} for amorphous SiO_2 films at room temperature. It is equal to and slightly organ with decreasing temperature. This value is significantly smaller than the values reported for SiO_2 amorphous films (N_e =$4\div6\cdot10^{20}$ cm^{-3}) sputtered on a silicon wafer. This low mobility can be attributed to the structural disorder inherent in amorphous dielectric compounds, which disperse charge carriers weakly. For $CrSi_2$ films at room temperature N_e=$1.584\cdot10^{23} \pm 0.3\cdot10^{23}$ cm^{-3}, n_{sh}=$1.44\cdot10^{22} \pm 0.4\cdot10^{22}$ cm^{-2} and μ_H=21.87 ± 0.04 cm$^2\cdot$V$^{-1}\cdot$s^{-1} is equal to. The mobility values range from μ_H=3412.90 ± 0.8 cm^2 V^{-1} s^{-1} to μ_H=3697.40 ± 0.12 cm^{2}V^{-1}s^{-1} for 80 nm thick films, respectively. These values remain significantly lower than those measured in the mass analogue.

Analysis of the research results shows that the $CrSi_2$ thin film can be widely used as a semiconductor element to replace materials with p-type physical properties, as well as as active parts of modern micro- and nanoelectronic devices in the future.

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