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Ion Induced Silicide Phase Formation in Ni—Si System

Wytwarzanie fazy krzemków przez wiązkę jonową w układzie Ni—Si

Образовние фаз силицидов индуцированное ионами в системе Ni—Si

1. INTRODUCTION

Nickel forms following dominant phases of silicides: Ni_2Si NiSi and $NiSi_2$. These phases can be obtained by the thermal annealing at temperatures above 200°C in vacuum or in inert gas atmosphere [1]. The another method of the formation of thin silicide films is ion beam induced reactions [2 - 5]. Atomic mixing induced in solid targets by ion bombardment is a novel technique used to the formation of crystalline and amorphous phases of many compounds, metastable phases and solid solutions. During the last few years the mixing method is intensively investigated, but the basic mechanisms of the atomic transport are still not well understood [2 - 4].

By using Rutherford backscattering techniques (RBS) we have investigated the formation of silicide layers induced by the interaction of the noble gas ion beams with the nickel thin film - silicon single crystal (Ni - Si) structures.

2.EXPERIMENTAL

The Ni-Si structures were prepared by vacuum evaporation ($p \cong 10^{-6}$ mmHg) of nickel on (100) oriented, 300 μm thick Si substrates. Before the deposition of Ni films Si samples were etched in CP4A solution and rinsed in deionized water.Since than, silicon samples were etched in $HF+H_2O$ solution to remove the surface silicon oxide layers, rinsed in deionized water and dried in air. The thickness of Ni films was ~ 45nm and during the deposition was controlled by a quartz oscillator. The bombardment of Ni-Si structures was carried out in the following way: a part of samples were implanted by 120 keV Ar ions up to the dose of 2×10^{16} i/cm^2 and a second part of samples were implanted by 300 keV Xe^{++} ions up to the dose of 2×10^{16} i/cm^2. The energies of incident ions were chosen in such a manner that the thickness of Ni film was greater than $R_p - \Delta R_p$ and less than $R_p + \Delta R_p$, where R_p is the projected range of indicent ions and ΔR_p is the standard deviation.

Implanted and unimplanted Ni-Si structures were investigated by using 2.5 MeV ^{4}He ion backscattering techniques (RBS). . The scattering angle was 135°. The RBS measurements were performed at the Laboratory of Neutron Physics of the Jonit Institute of Nuclear Reserach in Dubna (USSR).

Random RBS spectra were analyzed using the RBSM computer simulation program. In the initial system model the Ni-Si structure was decomposed on the several thin layers with the various values of the Ni atomic concentration relative to the concentration of Si atoms (N_{Ni} / N_{Si}).If the model was suitably chosen (number of layers, thickness of layers and N_{Ni} / N_{Si} values) the RBSM program would allow to obtain the good agreement between the experimental and theoretical spectra. Because of small values of film thicknesses the surface energy approximation model [6] was used to calculate the theoretical RBS spectrum. In the calculations the values of $No_{Ni} = 9.14 \times 10^{22}$ atoms/cm^3 and $No_{Si} = 5.00 \times 10^{22}$ atoms/cm^3 were used as the atomic concentration in pure Ni film and Si single crystal, respectively.

3.RESULTS AND DISCUSSION

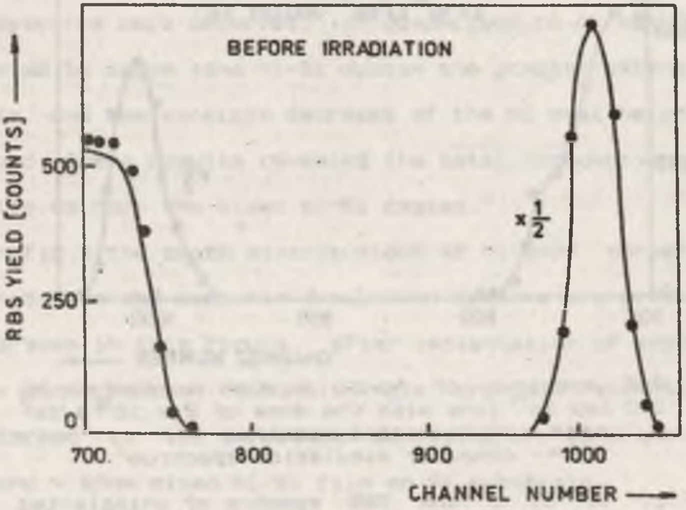

Fig.1 RBS spectrum of Ni-Si system before irradiation
●●●●●- experimental spectrum
——— - computer simulation spectrum

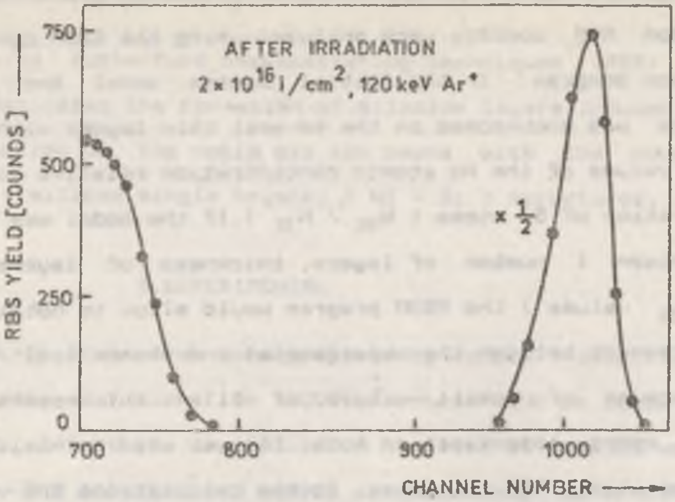

Fig.2 RBS spectrum of Ni-Si system implanted by 120 keV Ar$^+$ ions with the dose of 2×10^{16} i/cm^2
●●●● - experimental spectrum
——— computer simulation spectrum

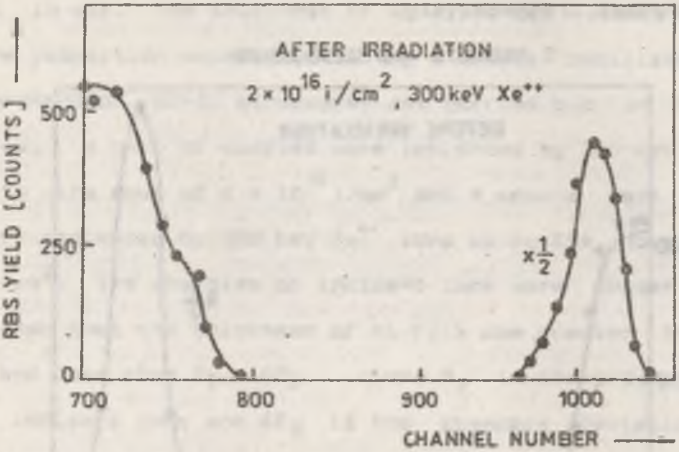

Fig.3 RBS spectrum of Ni-Si system implanted by 300 keV Xe^{++} ions with the dose of 2×10^{16} i/cm^2
●●●● - experimental spectrum
——— - computer simulation spectrum

In Fig. 1, 2, 3 the RBS spectra of unimplanted and implanted Ni-Si structures are presented. The dotted lines show the experimental spectra , the solid lines show the computer simulation spectra. The good agreement between theoretical and experimental spectra was obtained.

The influence of the ion implantation on RBS spectra was noticed in the extension RBS signals. The Si signal extended to the higher energies and Ni ones to the lower energies. These extension were caused by the mixing of Ni and Si atoms as the result of the Ar and Xe ion implantation.

In the case of the 120 keV argon ion implantation with the dose of 2×10^{16} i/cm^2, Fig.2, the height of Ni peak is comparable to the height of Ni peak of the unimplanted Ni-Si structure, Fig.1. This result indicatesthat a part of the Ni surface film remained unmixed.

In the case of the 300 keV xenon ion implantation with the dose of 2×10^{16} i/cm^2,Fig.3, the various features in the RBS spectrum were observed. In comparison to Ni peak of the implanted by argon ions Ni-Si system the greater extension of signals and the sensible decrease of the Ni peak height were observed. These results revealed the total consumption of nickel film to form the mixed Ni-Si region.

In Fig.4 the depth distributions of Ni atom concentration obtained from the computer simulation spectra are presented.As it is seen in this figure, after implantation of argon ions the ~ 45nm Ni(thin film)-Si(single crystal) structure was transformed to the structure consisted of ~ 25nm unmixed Ni film and ~ 60nm mixed Ni/Si film on Si substrate.

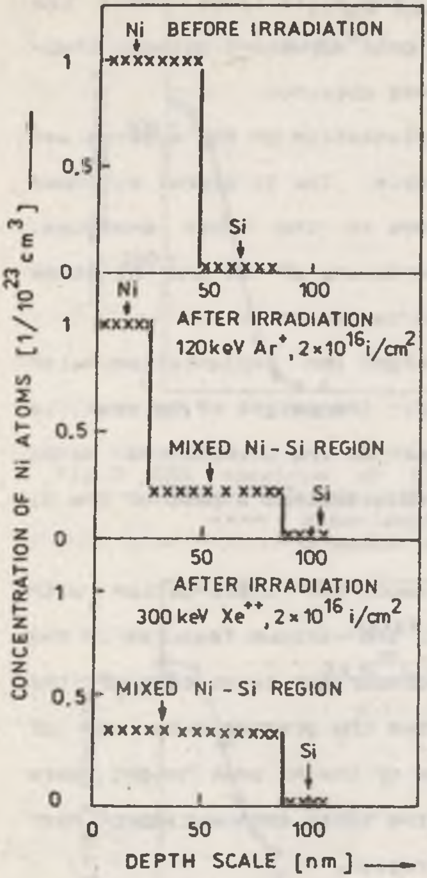

Fig.3 Computer simulated depth distributions of Ni atoms concentration in unimplanted and implanted Ni-Si systems

The concentration of Ni atoms in the mixed Ni/Si film decreased to the value of 2.1×10^{22} cm^{-3} in comparison with the Ni atom concentration in pure Ni. The relative concentration N_{Ni} / N_{Si} was 0.5, it corresponds to the NiSi compound. After the xenon ion implantation the initial Ni-Si structure was transformed to the ~90 nm thick mixed Ni/Si film on Si substrate. The Ni atom concentration was 3.5×10^{22} atoms/cm^3 and the ratio N_{Ni}/N_{Si} was 1.0 in the mixed Ni/Si film. This value of N_{Ni} / N_{Si} corresponds to the NiSi compound. As an evidence of the sputtering of the surface Ni layer during ion implantation the decrease of the number of Ni atoms was observed. The sputtered Ni film fraction was 18-20 % for xenon ions and was two times less for argon ions. Similar effects of the surface sputtering in Pd-Si and Sn-Si structures were observed in the paper [3] for argon ion implantation with the dose above 10^{16} i/cm^2.

The mixing of Ni-Si structures was more effective for heavy ion implantation. The dose of 2×10^{16} i/cm^2 of 300 keV Xe ions mixed totally ~45 nm Ni film with Si, but the same dose of 120 keV Ar ions is unsufficient for the transformation of all Ni film to the mixed Ni/Si region. The change of the N_{Ni}/N_{Si} value from 0.5 for argon ions to 1.0 for xenon ions is associated with the larger value of recoil yield for heavier ions. Consequently the composition of mixed Ni/Si films depends on the transition of Ni atoms into Si substrate and the increase of N_{Ni}/N_{Si} ratio for heavier ions was observed.

In addition the X-ray diffraction measurements of Ni-Si structures were carried out. These studies did not indicate the formation of the crystalline phase of nickel silicides. The formed Ni/Si mixed films were amorphous. The formation of amorphous phases of nickel silicides was also observed in the paper [2].

4. CONCLUSIONS

At room temperature ion implantation with 120 keV Ar ions or 300keV Xe ions and dose of 2×10^{16} i/cm^2 in ~45 nm Ni-Si structure caused the formation of amorphous thin mixed silicide layers with the tchickness of a few tens nm. The composition of the mixed region depends on the transition of Ni atoms in silicon substrate.

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STRESZCZENIE

Metoda mixingu cienkich warstw ciał stałych z podłożem pod wpływem implantacji jonów jest nową metodą wykorzystywaną do otrzymywania wielu związków, metastabilnych faz i stopów. W niniejszej pracy przedstawiono wyniki badań procesu mixingu układów: cienka warstwa niklu-monokryształ krzemu (Ni-Si) pod wpływem implantacji jonami gazów szlachetnych. Układy Ni-Si były badane metodą rozpraszania wstecznego cząstek α (RBS) i dodatkowo metodą dyfrakcji promieni X. Widma RBS były analizowane przy użyciu programu RBSM symulującego teoretyczne widma.

Przeprowadzono implantacje układów Ni-Si jonami Ar o energii 120 keV lub Xe o energii 300 keV dawką 2x10^{16} i/cm^2 w temperaturze pokojowej. Na skutek bombardowania warstwy ~45 nm Ni na monokrysztale Si powstały amorficzne warstwy krzemków niklu o grubości kilkudziesięciu nm, przy czym o składzie zmieszanych warstw decydował proces transportu atomów Ni do podłoża Si.

РЕЗЮМЕ

Метод смешивания тонких пленок твердых тел с подложкой под влиянием внедряемых ионов - это новый метод, использованный для получения многих соединений, метастабильных фаз и сплавов. В данной работе представлены результаты исследований процесса смешивания систем: тонкая пленка - монокристалл кремния (Ni-Si) под влиянием внедряемых ионов благородных газов. Системы Ni-Si исследовались методом обратного рассеяния α-частиц (RBS), а также дифракцией Х-лучей. Спектры RBS анализировались с помощью программы RBSM, моделирующей теоретические спектры. Проводилась имплантация Ni-Si-систем ионами аргона или ксенона с энергиями I20 и 300 кэВ, соответственно, дозой 2xI0^{16} ион/см^2, при комнатной температуре. Вследствие бомбардировки пленки ~45 нм в монокристалле Si - образовались аморфные слои силицидов никеля толщиной в несколько десятков нм; состав смешанных слоев определялся прежде всего процессом переноса атомов Ni в подложку Si.