Concentration microprofiles in iron silicides induced by low energy 
$\text{Ar}^+$ ion bombardment

Zexian Cao *, Hans Oechsner

Department of Physics, University of Kaiserslautern, Kaiserslautern D-67663, Germany

Received 11 August 1999; received in revised form 16 November 1999

Abstract

Auger electron spectroscopy (AES) in conjunction with sputter removal by $\text{Ar}^+$ ions of only 120 eV has been used to determine the concentration microprofiles generated in polycrystalline Fe$_3$Si, FeSi and FeSi$_2$ samples by a preceding bombardment with $\text{Ar}^+$ ions of 1–5 keV. The conversion of the surface sensitive AES ptp-signals measured in dependence of the profiling ion fluence into concentration-versus-depth profiles was facilitated by the fact that the bombardment-induced stoichiometry changes had no noticeable influence on the relative AES detection factors between Si and Fe. The concentration microprofiles extended up to about 16 nm into the solid, and displayed a rather uniform behaviour with a pronounced minimum of the Si concentration at 1–2 nm. Their characteristic features are related to the mean projected ranges of the keV-projectiles in the different iron silicides, and are assumed to provide direct experimental information on the corresponding deposited energy functions. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Ion–solid interaction; AES sputter depth profiling

1. Introduction

Compositional modification of solid surfaces through the interaction with low energy ions is of great interest in many areas as, e.g., sputter depth profiling or ion assisted thin film deposition [1,2]. The surface-near region of a multi-component target will change under ion bombardment until a steady-state concentration microprofile is formed which, depending on the bombarding ion energy, extends to some ten atomic spacings into the bulk [3]. It has been well established that a number of physical processes such as cascade mixing, preferential sputtering, or radiation enhanced diffusion and segregation contribute to the formation of the concentration microprofiles. The related phenomena are extensively discussed in [4,5].

Auger electron spectroscopy (AES) as a surface sensitive method for composition analysis in conjunction with controlled sputter removal provides an appropriate means to investigate depth-depen-
dent elemental concentrations in multi-component samples. In AES sputter profiling, however, two conditions have to be fulfilled in order to achieve a depth resolution which enables the analysis of very shallow concentration profiles: first, Auger electrons with energies referring to a minimum escape depth have to be employed; and second, the distortion of the original concentration profile by the profiling ions has to be minimized. The latter condition requires a sufficiently low ion bombarding energy at which only the actually outermost atomic layers are attacked.

The present study refers to the investigation of concentration microprofiles being established in three different iron silicides (Fe₃Si, FeSi and FeSi₂) under pre-bombardment with normally incident Ar⁺ ions of 1–5 keV. These three silicides cover a rather wide range of bulk composition, and thus are expected to reveal the influence of the bulk concentration on the different effects influencing the formation of the bombardment-induced concentration microprofiles.

We describe at first the experimental technique employed for AES sputter depth profiling at a sputtering energy in the 10² eV regime. Second, the results for the surface concentration-versus-ion fluence profiles will be converted into the ‘true’ concentration depth profiles by an appropriate evaluation procedure. Characteristic features of the steady-state microprofiles will be discussed with respect to the energy of the profile generating ions and the sample stoichiometry, whereas the mechanism of profile formation will be addressed in a subsequent paper by a corresponding model being developed there.

2. Experimental

A schematic of the experimental arrangement is presented in Fig. 1. The sample is mounted on a rotary holder by which it can be turned in front of a commercial ion gun (Leybold IQE 12/38) which provides a raster-scanned Ar⁺ ion beam of several 10 μm in diameter at ion energies \(E_0\) from 1 to 5 keV. The bombarded sample area for the generation of the concentration microprofile was of the order of 1 cm². The sample was alternatively positioned in front of a cylindrical mirror analyser (CMA) with a coaxial electron gun providing a 3 keV primary electron beam with a diameter of the order of 10 μm, and in front of a special ion source for low energy sputter removal. The profiling Ar⁺ ions are provided by a low pressure (≤10⁻³ mbar) Ar-plasma being excited by electron cyclotron wave resonance (ECWR) [6]. When applying an r.f. potential between the bulk of this plasma and a high transparency metal grid, the plasma is expanded with its full density into an attached smaller chamber close to the sample surface. The plasma transport into that chamber is achieved with the same technique as for the formation of a plasma beam described elsewhere [7]. For sputter depth profiling a laterally homogeneous ion flux is extracted by a simple ion optics in the same way as for the so-called direct bombardment mode of electron gas SNMS [8]. Ion energies down to 50 eV can be established by this technique at current densities of 0.5–1.0 mA/cm².

The base pressure in the whole system containing the plasma chamber as an internal vessel was around 10⁻⁹ mbar. The samples consisted of polycrystalline Fe₃Si, FeSi and FeSi₂ (from CERAC) with a size of 1.2 × 2.0 × 0.2 cm³. They were mounted on a copper sample holder of high thermal and electrical conductivity. Before transferred into the ultrahigh vacuum via an introduction chamber with a base pressure of 3 × 10⁻⁸ mbar, they were mechanically polished with diamond paste and cleaned in an ultrasonic bath. After introduction they have been sputter cleaned with 2...
keV Ar$^+$ ions until the residual C(KLL) and O(KLL) Auger signals fell below the AES detection limit. The sample temperature has been controlled using a temperature sensitive resistor (PT100), and did not exceed 120$^\circ$C in all cases.

For optimum data processing the recorded direct Auger signals were subsequently smoothened and differentiated digitally according to the Savitzky–Golay algorithm [9]. Because of their high surface sensitivity the 47 eV Fe (MVV) and 91 eV Si (LVV) Auger transitions were used. The corresponding inelastic mean free paths (or mean escape depths) of the respective Auger electrons calculated from the Seah and Dench formula [10] are given in Table 1 together with the mean atomic spacings of the three iron silicides under investigation.

In order to establish steady-state concentration microprofiles the sputter cleaned sample surfaces were always exposed to ion fluences being about twice as high as those for which the surface concentrations became stationary under the pre-bombardment with normally incident keV Ar$^+$ ions. An example is shown in Fig. 2 for the FeSi$_2$ sample. First, the good reproducibility of the surface conditions for an individual bombarding energy ($E_0 = 1$ keV) are demonstrated. Second, it is interesting to note that the surface concentration of Si increases steplike when the bombarding energy $E_0$ is raised from 1 to 3 keV or 5 keV. During the respective short time intervals about four atomic layers are estimated to be sputter removed. Subsequently the surface sensitive Auger signal drops until the new steady-state conditions are achieved. This behaviour can be explained with the difference between the damage production rate and the depth distribution of radiation damage. When assuming the nuclear stopping power to be proportional to $E_d^\delta$ with $0 < \delta < 1.0$ in the low keV regime [11], the depth distribution of the bombardment-induced damage shifts into the bulk with increasing $E_0$. The initial rise of the Si-surface concentration can be ascribed to the radiation enhanced surface segregation of Si. With increasing fluence the excess Si is sputter removed, and the surface concentration approaches the steady-state value for the individual bombarding energy $E_0$ [12].

After steady-state conditions have been reached, the samples have been AES sputter depth-profiled with the above described plasma ion source. Of course, the ion energy for depth profiling analysis must be chosen low enough for keeping the distorted depth small against that from the preceding keV-bombardment. For related quantitative information the range distributions of normally incident Ar$^+$ ions of 150 eV, 1, 3 and 5 keV have been calculated with the ‘SUSPRE’ code [13] for the monosilicide FeSi (Fig. 3). While a profiling energy of 150 eV appears still too high compared to the range distribution for 1 keV, sputter etching with less than 100 eV was found to cause strong preferential sputtering which may then veil details of the concentration microprofiles under investigation. Hence, 120 eV was chosen as

![Fig. 2. Variation of the Si concentration $C_S^\infty$ at the surface of an FeSi$_2$ sample under normal bombardment with Ar$^+$ ions of different energy. The arrows indicate where the ion energy is changed.](image-url)
a compromise. For this energy the current density of the profiling Ar$^+$ ions was kept at 0.4 mA/cm$^2$.

3. Auger sputter depth profiling

The measured AES sputter depth profiles for the three investigated iron silicides are presented in Fig. 4(a)–(c). The ptp-intensities of the differentiated Auger peaks of the 47 eV Fe (MVV) and the 91 eV Si (LVV) transitions are plotted versus the fluence of the profiling 120 eV Ar$^+$ ions. All profiles display the same characteristic behaviour with an inverse variation of the Fe- and the Si-signals. They reveal a maximum or a minimum for Fe or Si, respectively, thus demonstrating the formation of concentration microprofiles under the preceding keV-bombardment with an enrichment of Fe and a depletion of Si in the selvedage of the samples. The profiling ion fluences referring to the strongest composition change shift with increasing pre-bombarding energy $E_0$ clearly to higher values.

3.1. Quantification of AES signals

The Auger signals refer to the composition of the first 1–2 atomic layers at the actual surface because of the small escape depth of the Auger electrons (see Table 1). They are converted to concentrations by the following procedure. The Auger signal intensities $I_X$ of an element $X$ are related to the average concentration $C_X$ across the information depth by

$$C_X = r_X I_X,$$

where $r_X$ is the corresponding detection factor with theAuger electron spectrometer employed. For a binary target with components $X = A, B$, i.e., with $C_A + C_B = 1$, one obtains readily

$$r_{BA} I_A + I_B = \text{const.},$$

where $r_{BA} = r_B / r_A$ is the relative detection factor of B in respect to A. When $r_{BA}$ is independent of $C_A$ and $C_B$, the mean concentration of A within the information depth is obtained from $I_A$ and $I_B$ by

$$C_A = \frac{r_{BA} I_A}{r_{BA} I_A + I_B}.$$

This evaluation procedure is justified when the Auger intensities $I_A$ and $I_B$ measured during depth profiling are linearly correlated according to Eq. (2). The numerical value of $r_{BA}$ entering Eq. (3) is then given by the slope of the correlation lines.

As being demonstrated in Fig. 5 for FeSi$_2$ as an example, $I_{Fe}$ and $I_{Si}$ are sufficiently well linearly correlated for all Auger intensity versus fluence profiles in Fig. 4. This indicates that the chemical binding conditions (or the electronic configuration) of the surface of a certain silicide sample do not change noticeably under the pre-bombardment with the keV-ions. The slopes of the individual correlation plots differ only slightly at different pre-bombarding energies. Averaging over the slopes of the correlation plots the corresponding relative detection factors $r_{Si,Fe}$ are found to be 2.31, 2.28 and 2.10 for Fe$_3$Si, FeSi and FeSi$_2$, respectively. The small differences between these values can be ascribed to a slight dependence of the shape of the direct 91 eV Si-peak on the density of states in the valence band. While the energy distance between the maximum and minimum in the differentiated spectrum is almost identical (6.92 ± 0.02 eV) for the 47 eV Fe (MVV)-Auger transition, that for the 91 eV Si (LVV)-transition in Fe$_3$Si, FeSi and FeSi$_2$ amounts to 8.20, 8.61 and 9.16 eV, respectively. Since the 91 eV Si-peak in
Fig. 4. Auger sputter depth profiles of (a) Fe₃Si, (b) FeSi and (c) FeSi₂ after pre-bombardment with normally incident Ar⁺ ions of 1–5 keV. The ptp-intensities of the 47 eV (MVV) Fe- and the 91 eV (LVV) Si-peaks are plotted versus the fluence of profiling Ar⁺ ions.
silicon-rich iron silicides is broader, Si is then less sensitively detected.

With the known relative detection factors $r_{Si,Fe}$ the ptp-intensities in Fig. 4(a)–(c) can be converted into the corresponding surface concentrations $C_{Si}^S$ of Si via Eq. (3) (and to that of Fe with $C_{Fe}^S = 1 - C_{Si}^S$). The resulting concentration-versus-fluence profiles for Si are presented in Fig. 6.

The surface concentration of Si at the beginning of the profiles, i.e. at $x = 0$, increases with increasing energy of the pre-bombarding Ar$^+$ ions. Whereas for FeSi and FeSi the initial Si-concentration at the surface of the pre-bombarded samples are below the bulk concentration, this behaviour is reversed for the Fe-rich silicide Fe$_3$Si. Compared to FeSi and FeSi$_2$ a higher fraction of the incident energy is partitioned among the Fe atoms in Fe$_3$Si. This will lead to a more efficient sputter removal of Fe atoms. In order to establish

![Fig. 5. Correlation plots of the Si and Fe ptp-Auger intensities from Fig. 4(c).](image)

![Fig. 6. Si concentration $C_{Si}^S$ at the receding surfaces of the pre-bombarded iron silicides versus the fluence of the normally incident 120 eV Ar$^+$ ions for sputter profiling. The profiles for pre-bombardment with 2–5 keV Ar$^+$ ions are sequentially shifted along the fluence axis by a constant value of $1 \times 10^{17}$ ion/cm$^2$ for Fe$_3$Si and FeSi and of $3 \times 10^{17}$ ion/cm$^2$ for FeSi$_2$ for clearer presentation.](image)
stoichiometric sputtering, this must obviously be balanced by an increase of the Si concentration at the surface over that in the bulk. However, when comparing absolute values, $C^S_{\text{Si}}$ at $x = 0$ for Fe$_3$Si is still lower than for the two more Si-rich silicides.

The steady-state surface concentrations of Si under sputter removal with the profiling 120 eV Ar$^+$ ions are always below the corresponding bulk concentrations. They approach 19.8, 24.1 and 34.0 at.% in Fe$_3$Si, FeSi and FeSi$_2$ respectively, demonstrating the strong preferential sputtering of Si at low bombarding energies. The fluence of the 120 eV Ar$^+$ ions required to reach the steady-state concentrations increases with the Si bulk concentration. They extend from $5 \times 10^{17}$ ions/cm$^2$ for Fe$_3$Si under 1 keV Ar$^+$ ion pre-bombardment to $3 \times 10^{18}$ ions/cm$^2$ for FeSi$_2$ at 5 keV.

3.2. Conversion into concentration-versus-depth microprofiles

For the conversion of the surface concentration-versus-fluence profiles (Fig. 6) into the original composition depth profiles $C(x)$ in the pre-bombarded samples, we reformulate an evaluation procedure proposed by Ho et al. [14]. The profiling low energy ions (120 eV Ar$^+$) are assumed to alter the sample composition only within a very shallow depth interval $\Delta x$ given by their mean penetration length in the respective sample. Since for the present experimental conditions the mean projected range of the profiling Ar$^+$ ions compares well with the information depth of the Auger signals, the surface concentration $C^S_A$ can be taken also as the average value of the concentration of a sample constituent A across $\Delta x$. As another approximation, a constant total bulk density $N_0$ is assumed throughout the individual sample.

The mass balance equation for the constituent A of a binary solid AB within the interval $\Delta x$ at the receding surface reads

$$
\frac{d}{d\Phi} [\Delta x C^S_A(\Phi)] = v_{\text{spatt}}(\Phi) C_A(\Delta x + x)/J_0 - Y_{\text{tot}} C^S_A(\Phi)/N_0,
$$

where $\Phi = J_0 t$ is the fluence of the profiling Ar$^+$ ions (120 eV) at constant current density $J_0$ (0.4 mA/cm$^2$), $C_A(\Delta x + x)$ is the desired original concentration always at a depth $\Delta x$ below the actual position $x$ of the receding surface starting at $x = 0$ for $\Phi = 0$. Note that the influence of the preferential sputtering effect by the profiling ions is accounted for in Eq. (4) by considering the measured surface concentrations $C^S_A(\Phi)$.

The velocity $v_{\text{spatt}}(\Phi)$ of the receding sample surface is given by

$$
v_{\text{spatt}} = J_0 [Y^c_A C^S_A(\Phi) + Y^c_B C^S_B(\Phi)]/N_0,
$$

where $Y_{ab}^c$ are the component sputtering yields of A and B. These quantities describe the ejection probabilities of atom A or B from a binary surface. They can be assumed to be concentration independent when the surface composition does not change too drastically and, even more important, when variations of the chemical binding conditions can be neglected as in our case (cf. Fig. 5). The depth below the initial surface at $x = 0$ of the pre-bombarded sample can be readily calculated from

$$x(\Phi) = J_0^{-1} \int_0^\Phi v_{\text{spatt}}(\Phi) d\Phi.
$$

Then, taking into account that

$$C_A(x = 0) = C^S_A(\Phi = 0),$$

the original concentration microprofile $C_A(x)$ can be derived from Eq. (4) with a “depth resolution” $\Delta x$, when the component sputtering yields $Y_{ab}^c$ are known.

The component sputtering yields can in principle be determined by a mass spectrometric analysis of the sputtered flux, e.g., by SNMS, in conjunction with in situ measurements of the actual surface composition, e.g., by AES. However, when equilibrium sputter conditions can be assumed to be approached sufficiently well, the partial sputtering yields of A and B are given by $Y_{ab} = C_{ab}^{\text{tot}} Y_{\text{tot}} = C_A^{\text{tot}} Y_{A,B}^c$ with $C_{ab}^{\text{tot}}$ being the bulk concentrations of A and B, and $Y_{\text{tot}}$ the corresponding total sputtering yield. The ratio between the two component sputtering yields is then given by

$$Y_A^c/Y_B^c = C_A^b/C_A^c C_B^b/C_B^c.
$$
Together with \( Y_{\text{tot}} = C_A^S Y_A^C + C_B^S Y_B^C \), Eq. (8) serves to determine any two quantities among \( Y_{\text{tot}} \) and \( Y_{\text{Si}}^C \) if the third one is known.

For metal silicides as PtSi and NiSi the Si component sputtering yield \( Y_{\text{Si}}^C \) has been found to be close to the total sputtering yield of amorphous Si for sputtering parameters comparable to the present ones [15]. Since the sputtering behaviour of iron silicides is not expected to differ significantly from that for nickel silicides in the linear cascade regime, \( Y_{\text{Si}}^C \) for the investigated iron silicides is supposed to agree sufficiently well with the total sputtering yield of amorphous Si under the same sputtering conditions. The corresponding value for \( Y_{\text{tot}} \) (Si amorphous) can be taken from [16] to be 0.08 Si atoms per Ar\(^+\) ion of 120 eV. Then \( Y_{\text{Fe}}^C \) for the three iron silicides can be calculated via Eq. (8).

For the conversion of the concentration-versus-fluence profiles \( C^S(\Phi) \) into the depth dependent microprofiles \( C(x) \) according to Eq. (4), different values for \( \Delta x \) have been used for a comparison. When 3 and 4 mean atomic spacings are chosen for \( \Delta x \), which correspond roughly to the mean projected range of 120 eV Ar\(^+\) ions in iron silicides according to the SUSPRE simulation (cf. Fig. 2), the concentration around the Si-minimum in the concentration microprofiles \( C(x) \) differs by less than 2%, whereas the difference in the tails of the profiles remains negligibly small.

The resulting concentration profiles \( C_{\text{Si}}(x) \) which have been obtained via Eq. (4) from the corresponding ion fluence (or sputter time) profiles are displayed in Fig. 7. For a better presentation, the individual profiles are shifted along the depth scale by a constant distance given in the figure caption.

4. Discussion of characteristic profile properties

All concentration microprofiles display the same characteristic features with a minimum of \( C_{\text{Si}} \) at a depth of a few atomic distances, followed by an increase of the Si-concentration to the bulk value of the respective iron silicide. When neglecting temperature induced diffusion and segregation at the low sample temperatures in the present study, the bombardment-induced concentration microprofiles in the initially homogeneous samples must originate from ballistic atomic...
displacement and replacement effects. At a depth $x$ the density of such events will be determined by the local value of the deposited energy function $F_D(E_0, x)$ resulting from the bombardment of the solid with particles of energy $E_0$. $F_D$ and its dependence on the bombardment parameters and the target properties are extensively discussed within the scope of random sputtering theory [11,17].

Along the range of the bombardment induced atomic collision cascades the number of particles displaced out from a depth interval with a high $F_D$ value will exceed those being transported back from a neighbouring interval with lower $F_D$. If the displacement probabilities of the constituents A and B of a binary solid differ, a relative depletion of the easier displaced component is expected to occur around the maximum of $F_D(x)$ [18]. According to the results in Fig. 7 Si is the more displaced component in the investigated iron silicides, and the minimum of $C_{Si}$ is supposed to indicate the maximum damage production in the samples, i.e., the maximum of $F_D$. For a more precise discussion structural changes and lattice relaxation obviously would have to be taken into account [19].

The position $x(C_{Si}^{\text{min}})$ of the minimum Si-concentration beyond the surface of the pre-bombarded silicide samples (Fig. 7) is depicted in Fig. 8 as a function of the energy $E_0$ of the profile generating keV-ions. All curves can be fitted by the relation

$$x(C_{Si}^{\text{min}}) = \text{const.} E_0^{0.4}. \quad (9)$$

Since from the theory of particle-solid interaction the functional behaviour of $F_D$ is found to be similar to that of the range distribution of the projectiles in a solid target [20], the position of the maximum of $F_D(E_0, x)$ can be assumed to be proportional to the mean projected range $R_p(E_0)$ of the projectiles [21]. The individual $R_p$-values for the normally incident keV Ar$^+$ ions in the different silicides have been calculated with the SUSPRE-code. In Fig. 9 the $x(C_{Si}^{\text{min}})$-values taken from Fig. 8 are plotted versus the calculated $R_p$. A relatively good linear correlation with

$$x(C_{Si}^{\text{min}}) \simeq 0.3 \ R_p, \quad (10)$$

is found in accordance with the present considerations, thus indicating that $x(C_{Si}^{\text{min}})$ can be taken as a measure for the position of the maximum of the corresponding deposited energy functions $F_D(E_0, x)$.

Albeit there is no well defined termination of the concentration microprofiles, their extent increases with the bulk concentration of Si. When introducing a characteristic depth $x_{95}$ at which $C_{Si}(x)$ has regained 95% of the individual bulk concentrations, it is found that $x_{95}$ for the microprofiles formed under 2 keV pre-bombardment, for instance, extends to 3.8, 6.3 and 8.1 nm in Fe$_3$Si, FeSi and FeSi$_2$, respectively. Also, the absolute reduction $(\Delta C_{Si})_{\text{max}}$ of the Si concentration at the minimum of the $C_{Si}(x)$-curves taken against the bulk value $C_{Si}^b$ increases with the Si-content of the respective silicide. When referring again to the 2 keV-results, $(\Delta C_{Si})_{\text{max}}$ amounts to about 8 at.% for Fe$_3$Si, 19 at.% for FeSi, and 24 at.% for FeSi$_2$. Since the shape of the individual $C_{Si}(x)$-curves is
very similar, the product \((\Delta C_{Si})_{max} \cdot x_{95}\) can be taken as a gross measure for the Si-loss from the samples. Referring again to the 2 keV-results as an example, \((\Delta C_{Si})_{max} \cdot x_{95}\) is found to increase almost linearly with the bulk concentration \(C_{Si}^{b}\). As a general result, the higher the Si content the stronger is the absolute Si depletion in the surface region being attacked by the keV-ion bombardment. This is again in accordance with the considerations on the influence of \(F_D\) in a target with different displacement probabilities of its constituents. The corresponding depth dependent information for steady-state conditions is provided by the concentration microprofiles in Fig. 7.

Considering again the similar depth-dependent behaviour of the microprofiles, the ratios between \((\Delta C_{Si})_{max}\) and \(C_{Si}^{b}\) can be taken as a measure for the relative amount of dislocated Si along the entire depth interval being distorted by the keV-ion bombardment. In accordance with the preceding finding that the Si-depletion increases with \(C_{Si}^{b}\), \((\Delta C_{Si})_{max}/C_{Si}^{b}\) changes only little for a certain pre-bombarding energy, and amounts, e.g., to about 0.36 for the 2 keV-profiles.

It should be noted that in other studies [22] the steady-state concentration profile for a Ni–9.5 at.\% Si alloy under 3 keV Ne\(^+\)-bombardment has been found to display an almost complete depletion of Si around a depth of several nm (see also [5]). This demonstrates again Si to be the more displaced or mobile constituent. Because of the elevated temperature in that case (500°C) the formation of the Si minimum was ascribed to the synergetic action of maximum bombardment induced damage rate together with Gibbsian and radiation enhanced segregation, the latter resulting both in an Si transport towards the surface.

5. Conclusions

The concentration microprofiles induced beneath the surface of the iron silicides Fe\(_3\)Si, FeSi and FeSi\(_2\) by Ar\(^+\) ion bombardment in the low keV-regime have been shown to become quantitatively detectable from the variation of surface sensitive AES-peaks under subsequent sputter removal. As the most important condition, such a low energy of the profiling ions has to be chosen that the additional compositional changes induced by them remain confined to the mean escape depth of the Auger electrons. Normal bombardment with Ar\(^+\) ions of only 120 eV fulfills such conditions in the present case.

From the correlation plots of the Fe- and the Si-Auger intensities the relative detection factors between Fe and Si have been found to be constant for the individual silicide samples. This facilitates the conversion of the AES-intensities measured in dependence of the fluence of the profiling Ar\(^+\) ions into the concentration-versus-depth profiles with a mass balance equation for the profiling process.

For the investigated iron silicides Si is found to be preferentially removed from a near-surface interval under normal bombardment with Ar\(^+\) ions.
in the energy range 1–5 keV. Within the bombardment attacked region beneath the surface the Si-atoms are displaced with a higher probability than Fe. The stationary microprofiles are characterised by a pronounced minimum of the Si-concentration at a depth of 1–2 nm, and extend to about 16 nm or 70 mean atomic spacings for the Si-richest target under 5 keV-Ar$^+$ ion bombardment. The total Si-depletion under stationary sputter conditions increases with the bulk concentration $C_{\text{bSi}}$ of Si. The fraction of displaced Si-atoms along the entire microprofiles is nearly independent of $C_{\text{bSi}}$. As the depth of the concentration minimum for Si can be correlated with the maximum of the deposited energy function $F_D$ for steady-state ion bombardment, the concentration microprofiles may also provide hitherto not available experimental information about depth dependent energy deposition under low energy ion bombardment.

**Acknowledgements**

One of us (Z.C.) was financially supported by a stipendium from the Volkswagen Foundation and the DFG-Graduiertenkolleg “Laser- und Teilchenspektroskopie” at the University of Kaiserslautern. The authors are grateful to A. Wucher, now at the University Essen (Germany), and Ralf Mueller for helpful discussions.

**References**


