Analysis of atomic depth profiles directly extracted from Rutherford backscattering data for co-sputtered and ion irradiated Au-Ni films

D. Datta ∗,1 and S.R. Bhattacharyya

Surface Physics Division, Saha Institute of Nuclear Physics, 1/AF Bidhan Nagar, Kolkata 700 064, India.

Abstract

Co-sputtered Au-Ni thin films having thickness of 30 nm were deposited on Si(100) substrates and irradiated with 160 keV $^{40}$Ar$^+$ under ambient condition at a number of fluences and analyzed using Rutherford backscattering spectrometry (RBS). The variation of Au signal counts in the RBS spectra with ion dose has been investigated. The distribution of Au, Ni and Si atoms over various depths within the as deposited and irradiated samples have been computed using the backscattering data by means of a direct analytical method. Au and Si profiles have been fitted with error function and the relative changes in variance for various ion fluences compared to that of as deposited profiles have been studied. The spreading rates of different constituents across the interface due to Ar ion impact have also been discussed.

Key words: Rutherford backscattering, depth profiling, Au-Ni co-sputtered film, ion irradiation

PACS: 82.80.Yc, 68.55.Ln, 61.72.Ss, 81.70.Jb
1 Introduction

As the dimensions of solid state devices are scaled down, it is becoming increasingly necessary to improve the performance of the interconnects and their electrical characteristics. Metal silicides have some advantages over pure metal contacts due to their low-electrical resistivity and good thermal stability and these silicides are extensively used in microelectronic devices as contact materials to the source/drain areas to control the Schottky barrier height [1–3]. Energetic ion beams, when penetrate through the interface of different materials, produce massive atomic transport across the interface which results in many stable, unstable or even thermodynamically non-equilibrium phase formation around the interface. Due to improved electrical and chemical properties of the ion irradiated materials, mixing of metal-metal or metal-semiconductor systems using ion beam is frequently used to tailor different suitable contact materials for electronic devices [4, 5]. Ion bombardment induced composite formation in Au-Ni bilayer or multilayer films deposited on Si [6, 7] or III-V nitride semiconductors [8] have been proved to be an effective method to fabricate contacts having low resistivity (typically, $\sim 6 \times 10^{-4}$ $\Omega$-cm [9]).

Rutherford backscattering (RBS) technique is an easy and efficient tool to study the dynamics and atomic rearrangement around the interface. Analysis of RBS data and extraction of elemental depth profiles are mostly done using some standard codes [10–12] which are based on matching of experimental spectra with the theoretically simulated spectra of hypothetical sam-

* Corresponding author.  
Email address: debasish.datta@saha.ac.in (D. Datta ).  
1 Present address: Department of Physics, Electronics and Computer Science, Seth Anandram Jaipuria College, 10, Raja Naba Krishna Street, Kolkata - 700 005, India.
ple structures having multiple layers of different compositions. This type of indirect depth profiling is a difficult and time-consuming job sometimes leads to ambiguous results. Even for RBS spectra showing well separated peaks of constituent elements, this type of indirect method to synthesize atomic depth profiles is not always a trivial issue specially when the number of layers in the hypothetical sample is large or when one investigates the accumulation/depletion of a particular element over a small region inside the sample.

The aim of the present study is to implement a direct method to extract the depth profiles of the constituents from the Rutherford backscattering spectra and to get insight of the interactions between thin co-sputtered Au-Ni film and Si substrate during ion bombardment. The extracted concentration profiles of such a system and its analysis allows investigation of the mass transport of material across the interface during Ar ion irradiation, which may be important in the field of interconnects and contacts in the electronic device fabrication. Specially, relatively lower concentration of Ni in the system introduces control over the interface dynamics and formation of Au(Ni)Si alloy generated due to ion irradiation. In this study, we have shown the nature of impurity spreading into the matrix and subsequent broadening of interface due to 160 keV Ar$^+$ ion impact.

2 Experimental details

Thin metallic films of co-sputtered Au and Ni were grown on cleaned and polished Si(100) substrates in Ar atmosphere by dc magnetron sputtering. Prior to the deposition, the Si substrates were etched using HF solution to remove the native oxide layer from the surface. Before Ar introduction in
the deposition chamber to create plasma necessary for sputtering the base
pressure of the chamber was $8 \times 10^{-7}$ mbar. The deposition was carried out
at room temperature and the pressure of the chamber during deposition was
$9 \times 10^{-3}$ mbar. During deposition, both the Au and Ni sources were operated
simultaneously with same power to get uniformly mixed single layer of Au and
Ni over the substrates. However, different sputtering rates of these elements
gave rise to unequal stoichiometric composition within the films with 90 at%
Au and 10 at% Ni. Thickness of the deposited layer was $\sim 30$ nm as measured
using x-ray reflectivity technique. The deposited samples were then irradiated
with 160 keV $^{40}$Ar$^+$ ions using high current ion implanter (Danfysik) facility
of Saha Institute of Nuclear Physics. A schematic diagram and details of the
facility can be found elsewhere [13]. The fluences of the implanted ions were
varied from $5 \times 10^{14}$ to $5 \times 10^{16}$ ions/cm$^2$ and the pressure in the target
chamber was $3 \times 10^{-7}$ mbar. Homogeneous irradiation was achieved by means
of a magnetic X-Y beam scanning system. No special arrangement was made
to control the temperature of the samples during implantation but the beam
current was kept low to avoid beam heating induced atomic transport within
the sample. Depending on the attainable ion fluences, the ion beam fluxes were
kept around 400 nA/cm$^2$. The projected range of Ar ions in the target was
determined using SRIM2006 code. The irradiated samples were analyzed by
means of Rutherford backscattering spectrometry (RBS) using 2.05 MeV He$^{2+}$
ions obtained from the Pelletron of Institute of Physics, Bhubaneswar. The
backscattered data was collected using a silicon surface barrier detector with
16 keV resolution placed at 160°. Corresponding depth profiles were extracted
from the RBS spectra by direct method described in the following section.
3 Scheme of data analysis

The depth profiles of the constituent elements have been extracted directly from the backscattering data by a computer program written using MATLAB package. The method is particularly suitable for this system as the peaks corresponding to different elements are separated and well resolved. The direct determination of stoichiometry of the ion irradiation induced atomically mixed layer ensures accurate determination of elemental composition at various depths compared to other indirect simulation based standard codes. However, using both the above-mentioned procedures for a given analysis could be very convenient and helpful to avoid misinterpretation of the results.

Under this data analysis scheme, different elemental edges for the incident He\(^{2+}\) ion energy \(E_0\), which is 2.05 MeV in this case, are calculated and tracked in the experimental spectra using the relation \(k_x E_0\), where \(k_x\)'s are the kinematic factors with \(x\) representing the major elements present in the sample, namely, Au, Ni and Si. The signal height \(H_x(k_x E_0)\) of an element \(x\) (= Au, Ni or Si) at its respective edge is given by [15]

\[
H_x(k_x E_0) = \sigma_x(k_x E_0)Q \Omega N_{x_{mix}} \tau_x / \cos \theta
\]

(1)

where \(\sigma_x(k_x E_0)\) is the differential Rutherford scattering cross sections of element \(x\) at energy \(k_x E_0\), \(Q\) is total amount of charge accumulated on the sample due to He\(^{2+}\) incidence during the backscattering experiment, \(\Omega\) is the solid angle subtends by the solid-state detector at the sample and \(\theta\) is the angle subtends by the incident He beam with the surface normal (in the current setup \(\theta = 0^\circ\)). \(N_{x_{mix}}\) is the atomic density of element \(x\) in the mixture of Au, Ni and Si at the surface and \(\tau_x\) is the thickness of the imaginary surface.
layer inside the sample which is so chosen that the energies of He particles backscattered from this layer after colliding with atoms of element $x$ fall within the energy window $k_x E_0 - \xi$, where $\xi$ is the energy width of one channel of the detector. It is evident from the above fact that the depths $\tau$ for different constituents will be different depending on the concentration of a particular element in that mixture, respective kinematic factor and scattering cross section. The atomic density of the mixture $N^{\text{mix}}$ is given by the relation

$$N^{\text{mix}} = mN_{Au} + nN_{Ni} + pN_{Si}$$  \hspace{1cm} (2)

where $N$’s are the atomic densities of elements indicated by the subscripts and $m$, $n$ and $p$ are relative fractions of Au, Ni and Si respectively. If the presence of the implanted ions is neglected, the sum of all the atomic fraction is unity ($i.e. \; m+n+p = 1$) and in terms of relative fraction and atomic density, $N^{\text{mix}}_x$ can be expressed as

$$N^{\text{mix}}_x = mN_{Au}$$

$$N^{\text{mix}}_{Ni} = nN_{Ni}$$

$$N^{\text{mix}}_{Si} = pN_{Si}$$  \hspace{1cm} (3)

Using equation (3), the signal heights of the different elements present on the surface (equation (1)) can be modified as [15]

$$H_{Au}(k_{Au}E_0) = \sigma_{Au}(k_{Au}E_0)Q\Omega mN_{Au}\tau_{Au}$$

$$H_{Ni}(k_{Ni}E_0) = \sigma_{Ni}(k_{Ni}E_0)Q\Omega nN_{Ni}\tau_{Ni}$$

$$H_{Si}(k_{Si}E_0) = \sigma_{Si}(k_{Si}E_0)Q\Omega pN_{Si}\tau_{Si}$$  \hspace{1cm} (4) \hspace{1cm} (5) \hspace{1cm} (6)

The thicknesses corresponding to different elements expressed by $\tau_x$ are related to the stopping cross section factors of respective elements ($\left[\varepsilon(E_0)\right]^{\text{mix}}_x$) by the
expression [14]

\[ \tau_x = \frac{\xi}{[\varepsilon(E_0)]_{x}^{mix} N^{mix}} \]  

(7)

and the weighted sum of \( \tau \)'s gives the effective thickness of the layer:

\[ \tau = m\tau_{Au} + n\tau_{Ni} + p\tau_{Si} \]  

(8)

Therefore, equations (4)-(6) can be rewritten in terms of thickness and stopping cross section factor as

\[ H_{Au}(k_{Au}E_0) = \sigma_{Au}(k_{Au}E_0) Q\Omega m_{Au} \frac{\xi}{[\varepsilon(E_0)]_{Au}^{mix} N^{mix}} \]  

(9)

and so on.

Using the above mentioned expressions of signal heights of elements present within the surface layer \( \tau \), the ratio of relative fractions can be expressed as

\[ \frac{m}{n} = \frac{H_{Au}(k_{Au}E_0) \sigma_{Ni}(E_0) N_{Ni} [\varepsilon(E_0)]_{Au}^{mix}}{H_{Ni}(k_{Ni}E_0) \sigma_{Au}(E_0) N_{Au} [\varepsilon(E_0)]_{Ni}^{mix}} \]  

(10)

and

\[ \frac{m}{p} = \frac{H_{Au}(k_{Au}E_0) \sigma_{Si}(E_0) N_{Si} [\varepsilon(E_0)]_{Au}^{mix}}{H_{Si}(k_{Si}E_0) \sigma_{Au}(E_0) N_{Au} [\varepsilon(E_0)]_{Si}^{mix}} \]  

(11)

The ratios \( [\varepsilon(E_0)]_{Au}^{mix} / [\varepsilon(E_0)]_{Ni}^{mix} \) and \( [\varepsilon(E_0)]_{Au}^{mix} / [\varepsilon(E_0)]_{Si}^{mix} \) can be treated as unity in the first approximation and using the tabulated values of \( \sigma \)'s [15], relative concentration of each element has been estimated.

As the concentrations of all the elements within the depth \( \tau \) can be calculated using the above approximation, the values of \( [\varepsilon(E_0)]_{Au}^{mix} / [\varepsilon(E_0)]_{Ni}^{mix} \) and
\[ [\varepsilon(E_0)]_{Au}^{mix} / [\varepsilon(E_0)]_{Si}^{mix} \] can be extracted using the expression of stopping cross section factor of element \( x \):

\[
[\varepsilon(E_0)]_x^{mix} = \left[ \frac{k_x}{\cos \theta} \varepsilon_x^{mix}(E_0) + \frac{1}{\cos \phi} \varepsilon_x^{mix}(k_x E_0) \right] \tag{12}
\]

where \( \phi = 20^\circ \), in this experimental setup, is the complement of scattering angle and \( \varepsilon_x^{mix}(E_0) \) and \( \varepsilon_x^{mix}(k_x E_0) \) are the stopping cross sections of the mixture at energies \( E_0 \) and \( k_x E_0 \) respectively. The expressions of stopping cross section of the mixture for any given energy \( E \) is represented by

\[
\varepsilon^{mix}(E) = m \varepsilon_{Au}(E) + n \varepsilon_{Ni}(E) + p \varepsilon_{Si}(E) \tag{13}
\]

where \( \varepsilon_{Au}(E), \varepsilon_{Ni}(E) \) and \( \varepsilon_{Si}(E) \) are individual stopping cross sections of Au, Ni and Si respectively which are evaluated by the polynomial fit expressions [15]

\[
\varepsilon(E) = \sum_{i=0}^{5} A_i E^i \tag{14}
\]

with \( A_0 - A_5 \) being constants for a particular element when \( E \) is expressed in MeV.

Using equations (12) and (13), the stopping cross section factors for different elements are calculated and fed in equations (10) and (11) to calculate exact values of atomic fractions which values are again used in equations (12) and (13) in iterative manner to produce more accurate values of elemental concentrations in the layer.

As the thickness (\( \tau \)) and composition (\( N^{mix} \)) of the first layer is known, the energy, loses by the penetrating He ion while traveling through that layer can also be estimated and the energy of the ion just before entering the next layer
(E) is given by

\[ E = E' - \frac{\varepsilon_{mix}^{mix}(E')N_{mix}^{mix}}{\cos \theta} \]  

(15)

where \( E' \) represents the energy of the ion at the point of entering into the previous layer (\( = E_0 \), when dealing with second layer starting from surface). Simultaneously, signal heights of each element in the next lower channels starting from the corresponding elemental edges are also extracted. The ratios of atomic fractions in the second layer are given by

\[ \frac{m}{n} = \frac{H_{Au}(E_{Au}) \sigma_{Ni}(E) N_{Ni}}{H_{Ni}(E_{Ni}) \sigma_{Au}(E) N_{Au}} \left\{ \frac{\varepsilon(E)^{mix}_{Au}}{\varepsilon(E_{Ni})} \frac{\varepsilon(E_{Ni})}{\varepsilon(E_{Au})} \right\} \]  

(16)

and

\[ \frac{m}{p} = \frac{H_{Au}(E_{Au}) \sigma_{Si}(E) N_{Si}}{H_{Si}(E_{Si}) \sigma_{Au}(E) N_{Au}} \left\{ \frac{\varepsilon(E)^{mix}_{Au}}{\varepsilon(E_{Si})} \frac{\varepsilon(E_{Si})}{\varepsilon(E_{Au})} \right\} \]  

(17)

where \( H_{Au}(E_{Au}) \) is the height of Au signal in the channel preceding to that which corresponds to Au edge and \( E_{Au} \) is the energy equivalent of that particular channel. Similarly, \( H_{Ni}(E_{Ni}) \) and \( H_{Si}(E_{Si}) \) is the heights for Ni and Si signals respectively at channels next to Ni and Si edges towards the lower energy side. \( \varepsilon(E_{Au}) \) and \( \varepsilon(k_{Au}E) \) etc. are stopping cross sections at energies \( E_{Au} \) and \( k_{Au}E_{Au} \) and so on. \( \varepsilon(E)^{mix}_{x} \) is the stopping cross section factor for element \( x \) present in the mixture and expressed by the same relation as equation (12) with energy \( E_0 \) replaced by \( E \).

When treating the second layer, the approximation applied to the surface layer for determining the elemental composition is also valid which treats the values of the quantities within curly braces in equations (16) and (17) as unity. So, first estimation of the concentrations can be figured out using
that approximation which, in turn, can be used along with equation (14) and tabulated values of $\sigma$’s [15] in iterative manner to determine accurate values of elemental concentrations in that layer. Subsequent determination of $N^{mix}$ and $\tau$ for the layer can be done using equations (2), (7) and (8). For estimating elemental concentrations of third, forth and subsequent deeper layers, same formalism and expressions as applied to second layer can be followed.

It should be noted that experimentally obtained RBS spectra are convoluted with the apparatus function which contains initial beam energy dispersion, energy resolution of the detector, energy loss and energy-loss straggling in the detector as well as in the sample. But the determination of deconvoluted spectra using the normal deconvolution process is not trivial and sometimes introduces unwanted undulations in the spectra which may yield negative concentration of an element at some depth. So some other approaches described in ref. [16] or Bayesian probability theory [17] are suitable for recovering the ‘true’ spectra. Since the final aim of this paper is to investigate the relative broadening of Au and Si profiles with increased ion fluence in case of co-sputtered Au-Ni system, the effect of apparatus function causes unidirectional change in the RBS spectra and hence nullified.

4 Results and discussion

Figure 1 represents Rutherford backscattering spectra of as deposited and samples irradiated with Ar ions at different fluences. It can be observed from the figure that the Au signal height decreases with increasing dose which signifies sputter erosion of the films. On the other hand, Ni signals do not decrease significantly with increasing dose. This is due to the fact that higher

10
sputtering yield of gold triggers preferential sputtering of Au atoms within the mixture of Au and Ni. As a result, Ni signal heights decrease less rapidly than that of Au. Along with diminution of Au and Ni peaks, tailing of these signals towards lower energy side can also be observed representing ion irradiation induced atomic diffusion of constitutes in the direction of sample interior. The accumulation of Ar atoms which penetrate into the samples during ion irradiation, show no considerable change in the spectra until a dose of $1 \times 10^{16}$ ions/cm$^2$ beyond which a strong peak of Ar emerged between Ni and Si peaks. In contrast to the spreading of Au and Ni signals towards Si side, Ar peak at a fluence of $5 \times 10^{16}$ ions/cm$^2$ shows symmetry around its maximum position implying Gaussian type distribution commonly observed in case of implanted ions in solids at relatively low doses.

Variation of total counts enveloped by the Au signals in the RBS spectra with ion dose have been showed in figure 2. The total count for as deposited sample has been taken as unity and other counts are normalized with respect to that. The counts decrease rapidly at the initial stage of ion irradiation and after achieving a dose of $1 \times 10^{16}$ ions/cm$^2$ it becomes monotonous which is in accordance with the previously reported result regarding sputter erosion of thin films [18]. The data has been fitted using exponential decay function

$$C = C_0 + A \exp\left(-\frac{\text{fluence}}{B}\right)$$

where $C$ and $C_0$ are the normalized and saturated counts respectively and $A$, $B$ are constants. The fit gives the values of different parameters as $C_0 = 0.62 \pm 0.03$, $A = 0.36 \pm 0.04$ and $B = (27.98 \pm 11.09) \times 10^{14}$ ions/cm$^2$. The exponential decay of the Au counts with ion dose suggests that sputtering of thin films is different from that of bulk material. At the early phase of ion
bombardment the sputtering is to some extent analogous to bulk sputtering and the sputtering yields of Au and Ni for an ion-target combination as the present one are \( \sim 4.0 \) and \( \sim 0.5 \) atoms/ion respectively, as calculated using SRIM code. The outcome of larger yield for Au is a Ni-rich top layer along with surfacing of Si due to ion induced cascade mixing of the components which produces a saturated region in figure 26 above a critical dose of \( 1 \times 10^{16} \) ions/cm\(^2\).

The depth profiles of as deposited and irradiated samples as shown in figure 3 reveal the possible cause of exponential type decaying of integrated Au counts represented in figure 2. The depth profiles of as deposited and sample irradiated at a dose of \( 5 \times 10^{14} \) ions/cm\(^2\) show no significant difference with a presence of \( \sim 90\% \) Au and \( \sim 10\% \) Ni at the surface. After achieving a fluence of \( 1 \times 10^{15} \) ions/cm\(^2\), the sputter erosion of top surface layer is visible in the Au profile which is more noticeable at the next dose by the advancement of Si profile towards the surface. The Si concentration at the surface has reached around 15% for ion dose of \( 5 \times 10^{15} \) ions/cm\(^2\), with a reduction of the amount of Au. At higher doses the effect of preceding of Si profile is more dominant. Moreover, at a fluence of \( 1 \times 10^{16} \) ions/cm\(^2\), a surface layer of 10 nm having an approximate composition of \( \text{Au}_{58}\text{Ni}_{5}\text{Si}_{37} \) covering another layer of \( \text{Au}_{45}\text{Ni}_{5}\text{Si}_{50} \) which spreads over \( \sim 20 \) nm has emerged. At the next higher ion dose, \( i.e. \) at \( 5 \times 10^{16} \) ions/cm\(^2\), the buried compound layer has been exposed leaving completely mixed surface layer having a thickness of \( \sim 20 \) nm. The formation of mixed layers at the surface and subsurface regions at higher irradiation doses are responsible for saturation of Au signal count represented in figure 2. However, the Ni profiles at various fluences show very little observable changes due to irradiation.
The extracted atomic profiles has been used to quantify the growth of the mixed region due to ion irradiation. Au and Si profiles are fitted with error function to deduce the change in variance $\sigma^2$ as a function of ion dose. The relative change in variances ($\Delta\sigma^2$) for various doses with respect to the variance of Au profile for as deposited sample is represented in figure 4. A linear growth of the variance with the ion fluence had been observed previously in many metal/semiconductor systems due to ion irradiation [19–22]. But for the present system, the linear variation of $\Delta\sigma^2$ with ion dose seems to be valid only up to a fluence of $1 \times 10^{16}$ ions/cm$^2$. Beyond that $\Delta\sigma^2$ for both Au and Si profiles decrease to a lower value. The linear fit of present data up to $1 \times 10^{16}$ ions/cm$^2$ give the mixing rates $\Delta\sigma^2$/fluence = $6.88 \pm 0.77$ nm$^4$ for Au and $9.34 \pm 0.43$ nm$^4$ for Si. The difference in mixing rates is probably due to the diffusion of Ni atoms in Si layer which occurs simultaneously with Au. The lower heat of compound formation ($-16$ kJ/g at.) for Ni and Si and hence ready creation of different Ni-Si phases forms a physical barrier before the Au atoms to spread at an equal rate of Si. The decrease in $\Delta\sigma^2$ beyond $1 \times 10^{16}$ ions/cm$^2$ can be explained with the help of figure 2 and 3. The SRIM simulated range of impinging Ar ions is $\sim 125 \pm 65$ nm which is sufficient to deposit considerable energy on both sides of the interface and produces collision cascades. Collision cascades both in film and substrate regions set off recoil implantation, cascade mixing and radiation enhanced diffusion processes. Simultaneous preferential surface sputtering and cascade mixing not only form a Au-depleted surface but also an accumulation of Si around the near-surface region at and beyond $1 \times 10^{16}$ ions/cm$^2$ Ar dose (figures 3(e) and 3(f)). Eventually, the evolution of homogeneously mixed layer of Au$_{45}$Ni$_{5}$Si$_{50}$ which has been already discussed, contributes towards the sputtering process. The notable fact about these mixed layers is the absence of preferential sput-
tering of any species due to ion impact. The major components of the mixture, namely Au and Si are sputtered at the same rates which is supported by the SRIM simulation of similar kind of target composition-ion combination. The simulation provides the erosion yields of both Au and Si as $\sim 1.5$ atoms/ion and as a result, not any single component but the whole surface is sputtered away with ion impact. This fact is further supported by figure 2 which shows a flat region past a threshold dose. Thus, the bulk Si is becoming exposed which gives rise to lower values of $\Delta \sigma^2$ at an ion fluence of $5 \times 10^{16}$ ions/cm$^2$.

5 Conclusion

In this study, an efficient analytical method to analyze RBS data has been presented. Using that method, depth profiles of different components of co-sputtered and ion irradiated Au-Ni thin films on Si has been investigated. It has been observed that variation of $\Delta \sigma^2$ with dose follows a linear relationship up to a certain ion fluence which yields mixing rates of $6.88 \pm 0.77$ and $9.34 \pm 0.43$ nm$^4$ for Au and Si, respectively. The lowering of $\Delta \sigma^2$ values ahead of a critical dose can be explained by the formation of Au-Ni-Si composite at the surface from which elements are sputtered out evenly which is further supported by variation of Au counts in RBS spectra with ion dose.

6 Acknowledgement

The authors are indebted to Mr. S. Roy for the assistance in depositing film using the magnetron sputtering unit. They also thank all members of Ion Beam Laboratory of Institute of Physics, Bhubaneswar for RBS measurements.
References

[1] C. Lavoie, F.M. d’Heurle, C. Detavernier and C. Cabral Jr., Microelectronic Engineering 70 (2003) 144.

[2] Y.L. Jiang, A. Agarwal, G.P. Ru, G. Cai and B.Z. Li, Nucl. Instr. Meth. B 237 (2005) 160.

[3] S.H. Wang, S.E. Mohney and R. Birkhahn, J. Appl. Phys. 91 (2003) 3711.

[4] N. Bibic, V. Milinovic, K.P. Lieb, M. Milosavljevic and F. Schrempel, Appl. Phys. Lett. 90 (2007) 51901.

[5] K.P. Tai, N. Gao, X.D. Dai, J.H. Li, W.S. Lai and B.X. Liu, Appl. Phys. Lett. 89 (2006) 94108.

[6] F. Tamisier, C. Jaouen, J.P. Rivire, R. Durner, B. Heinz and P. Ziemann, J. Appl. Phys. 85(11) (1999) 7655.

[7] D. Mangelinck, P. Gas, A. Grob, B. Pichaud and O. Thomas, J. Appl. Phys. 79(8) (1996) 4078.

[8] C.Y. Hu et al., J. Cryst. Growth. 298 (2007) 808.

[9] J.K. Kim, J.H. Je, J-L Lee, Y. J. Park and B-T Lee, J. Electrochem. Soc. 147(12) (2000) 4645.

[10] E. Rauhala, N.P. Barradas, S. Fazinic, M. Mayer, E. Szilgyi and M. Thompson, Nucl. Instr. Meth. B 244 (2006) 436.

[11] R.L. Doolittle, Nucl. Instr. Meth. B 9 (1985) 344.

[12] J. Saarilahti and E. Rauhala, Nucl. Instr. Meth. B 64 (1992) 734.

[13] T.K. Chini, D. Datta, S.R. Bhattacharyya and M.K. Sanyal, Appl. Surf. Sci. 182 (2001) 313.
[14] R. Khalfaoui and S. Tobbeche, Vacuum 78 (2005) 141.

[15] W.K. Chu, J.W. Mayer and M.A. Nicolet, Backscattering spectrometry, New York: Academic Press: New York 1978.

[16] H. Ellmer and D. Semrad, Phys. Rev. E 54 (1996) 3569.

[17] R. Fischer, M. Mayer, W. von der Linden, and V. Dose, Phys. Rev. E 55 (1997) 6667.

[18] D. Datta and S.R. Bhattacharyya, Nucl. Instr. Meth. B 212 (2003) 201.

[19] G. Was, Prog. Surf. Sci. 32 (1989) 211.

[20] V. Milinovic, N. Bibic, K.P. Lieb, M. Milosavljevic and F. Schrempel, Nucl. Instr. Meth. B 257 (2007) 605.

[21] D. Datta and S.R. Bhattacharyya, Nucl. Instr. Meth. B 212 (2003) 216.

[22] M. Nastasi, J.W. Mayer and J.K. Hirvonen, Ion-Solid Interactions: Fundamentals and Applications, Cambridge University Press) 1996.
Figure captions

Figure 1: RBS spectra of (a) as deposited co-sputtered Au-Ni sample and samples irradiated using 160 keV $^{40}$Ar$^+$ with doses of (b) $5 \times 10^{14}$, (c) $1 \times 10^{15}$, (d) $5 \times 10^{15}$, (e) $1 \times 10^{16}$ and (f) $5 \times 10^{16}$ ions/cm$^2$. The upper and lower panels represent the same spectra but in the lower panel each spectrum is vertically shifted from others. The spectra are normalized with respect to Si signal height and different scales are used for Au and Ni/Si signals for clarity.

Figure 2: Integrated counts under Au signals in the RBS spectra of co-sputtered films. The counts are normalized with respect to that of as deposited sample. The data has been fitted using the equation of exponential decay.

Figure 3: Depth profiles of (a) as deposited co-sputtered Au-Ni sample and samples irradiated using 160 keV $^{40}$Ar$^+$ with doses of (b) $5 \times 10^{14}$, (c) $1 \times 10^{15}$, (d) $5 \times 10^{15}$, (e) $1 \times 10^{16}$ and (f) $5 \times 10^{16}$ ions/cm$^2$.

Figure 4: Change of variance of (a) Au and (b) Si profiles as a function of ion dose and linear fit (dotted line) of the experimental data.