Chapter - 4

Dependence of contact resistance, roughness, magnetization and melting on Ge content in the AuGe alloy

4.1 Introduction

The eutectic AuGe/Ni/Au Ohmic contact metallization gives low contact resistance of the order of $\sim 0.03 - 0.1 \ \Omega \cdot \text{mm}$ [1-10]; however, this is achieved at the expense of increased surface roughness [10]. The optimum Ni layer thickness for a 100nm AuGe layer thickness is $\sim 25-30$nm (chapter 3) and the surface roughness is $\sim 25$nm [10]. The surface roughness can influence the transistor gate fabrication (HEMT), while fabricating on-chip support circuits with Hall magnetic field sensors for various applications on GaAs/AlGaAs multilayer structures. The surface roughness can be reduced by increasing the Ni layer thickness above the optimum, at the expense of increased contact resistance (chapter 3) and possibly magnetism [10-14].

Alternative to increasing Ni layer thickness, for reducing the surface roughness is reduction of the Ge content below that of the eutectic composition (88:12 wt %). Ge however, is necessary for making the Ohmic contact, indiffusion of Ge dopes device layers forms a low resistance tunneling contact [15-19]. On the other hand, decreasing Ge content from the eutectic composition can increase the alloy melting temperature and could influence the surface roughness. Hence it is relevant to examine the effect of Ge content in the AuGe alloy on the surface roughness and contact formation.

In this chapter the following are studied:

1. The effect of Ge content in the AuGe alloy on the contact resistance and surface roughness using three AuGe compositions.
2. The effect of Ge content in the AuGe alloy on the melting in the metallization.
3. Study the residual magnetization of the processed Ohmic contact metallization (AuGe/Ni/Au) structure in the context of magnetic field sensor applications [20-22].
4. The effect of Ge content in the AuGe alloy layer on the transformation of Ni-layer to the non magnetic phase.
5. Low temperature dependence of contact resistance in the context of application of magnetic field sensor at low temperatures.

4.2 Dependence of contact resistance, roughness, magnetization and melting on Ge content in the AuGe alloy and Ni layer thickness.

In this section, the results of contact resistance, roughness, magnetization and melting in the metallization structure as functions of anneal temperature, Ni layer thickness and three AuGe compositions using annealed AuGe/Ni/Au film structures are presented.

4.2.1 Experimental

Three contacts are investigated with eutectic (88:12 weight %) and off-eutectic (95:5 and 97.3:2.7 wt %) compositions of the AuGe alloy. Temperature scan of Differential Scanning Calorimetry (DSC) are performed on the bulk alloy pieces from room temperature to 500°C at a heating rate of 100°C/min in N₂ gas atmosphere (figure 4.2.1). Each of the original data is subjected to an offset corresponding to its baseline and good homogeneity is obtained as seen by the data on the bulk alloy sample (figure 4.2.1). The melting temperature of AuGe (88:12wt%) alloy is 375.5°C, as shown in figure 4.2.1, and the melting temperature of the bulk alloy increased with decreasing Ge content from 12 wt% to 5wt% to 2.7wt% in the AuGe alloy (figure 4.2.1).

The Ohmic contacts are prepared by evaporating AuGe (100nm)/ Ni (30nm)/Au (200nm) using thermal and e-beam evaporation, onto wafer pieces with multilayer structure as shown in table 4.2.1. The Ni layer thickness of 30nm (close to the optimum for low contact resistance) is used for the Ohmic contact formation (chapter 3). The samples are then subjected to anneal at a temperature $T_A$ reached at heating rates of 250°C/min, held at $T_A$ for anneal durations $t_A$ in N₂ atmosphere.
The contact resistances are measured by lithographically patterning a transmission line pattern as described in [23] chapter 2, and using the Transmission line or Transfer Length Model (TLM) [23, 24]. Magnetization hysteresis loops are measured on samples with the annealed contact structures with several Ni layers thicknesses (25, 30, 50 nm) using Vibrating Sample Magnetometer (VSM). Temperature scans of Differential Scanning Calorimetry (DSC) are performed on the metallized substrate, with a bare substrate as the reference. The scan spanned from room temperature to 500°C at a heating rate of 100°C/min.

**Table 4.2.1 GaAs/AlGaAs wafer layer structure and Ohmic contact metallization**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au (200nm)</td>
<td></td>
<td>Ni (30nm)</td>
</tr>
<tr>
<td>Eutectic/off-eutectic AuGe alloy (100nm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n^+$ (Si 1.5 x $10^{18}$) GaAs</td>
<td>20nm</td>
<td>Cap layer</td>
</tr>
<tr>
<td>$n^+$ (Si 1.5 x $10^{18}$) Al$<em>{0.3}$GaAs$</em>{0.7}$</td>
<td>30nm</td>
<td>Supply layer</td>
</tr>
<tr>
<td>Intrinsic AlGaAs</td>
<td>15nm</td>
<td>Separation layer</td>
</tr>
<tr>
<td>Intrinsic GaAs</td>
<td>500nm</td>
<td>2DEG</td>
</tr>
<tr>
<td>Si GaAs Substrate</td>
<td>500µm</td>
<td></td>
</tr>
</tbody>
</table>

The surface roughness is estimated by measuring the root-mean-square height of the sample profile over an area of about 5µm×5µm, at several pads of the TLM structure.
using Dynamic Force Microscopy (DFM). Temperature dependence (4-300K) of the contact resistance is undertaken on a few samples to study the changes in the electrical contact conduction mechanism and also in the context of low-temperature applications of the magnetic field sensor.

4.2.2 Electrical characteristics

The contact resistance, $R_{TC}$, as a function of anneal temperature for three AuGe alloy compositions for optimized anneal durations is shown in figure 4.2.2. The $R_{TC}$ dependence on Ni layer thickness, optimized with respect to anneal temperature and time, for eutectic AuGe alloy is shown in the inset.

1. The contacts with AuGe (88:12 wt %) /Ni/Au show Ohmic behavior for anneal temperatures ($T_A$) above 350°C and contacts with AuGe (95:5wt %) /Ni/Au show Ohmic behaviour above 370°C (figure 4.2.3). At $T_A = 350°C$ the contacts with AuGe (95:5 wt%) /Ni/Au represent characteristics of a back to back reverse biased diodes (figure 4.2.3). AuGe (97.3:2.7 wt%) alloy resulted in a diode-like characteristic at $T_A$ below 400°C and showed Ohmic characteristic at $T_A$ above 400°C.

![Figure 4.2.2 Contact resistance ($R_{TC}$) Vs anneal temperature ($T_A$) for eutectic and off-eutectic alloys with Ni layer thickness ($x_{Ni}$) of 30nm.](image)
2. The lowest contact resistance is observed at $T_A$ of 400°C for AuGe (88:12 and 95:5 alloy), and a contact resistance $R_{TC}$ of 0.07±0.005 Ω-mm is observed for AuGe (88:12) /Ni-30 nm/Au and 0.17 ± 0.02 Ω-mm for AuGe (95:5) /Ni-30 nm/Au configuration for 90 second anneals (table 4.2.2). The quoted errors (table 4.2.2) are r.m.s deviation over several separate deposition runs.

3. The contact resistance increased by a few orders for AuGe (97.3:2.7)-100nm/Ni-30nm/Au-200nm (1.3 Ω-mm) when compared to AuGe (88:12)-100nm/Ni-30nm/Au-200nm (0.07±0.005 Ω-mm) and AuGe (95:5)-100nm/Ni-30nm/Au-200nm (0.17 ± 0.02 Ω-mm).

4. Increasing the annealing temperatures increases the contact resistance marginally (figure 4.2.2).

5. The optimum Ni layer thickness for low contact resistance is $\sim$25-30 nm for AuGe layer thickness of 100nm (chapter 3) [10].

6. $R_{TC} (T_A)$ has a lower value and shallower minimum (better process latitude for $T_A$) for AuGe composition near the eutectic.

7. Increasing the Ni layer thickness and decreasing the Ge content in the alloy from the eutectic increases the contact resistance (table 4.2.2).
The dependence of the contact resistance of AuGe/Ni/Au alloyed contacts on anneal durations with various Ge content in the alloy is shown in figure 4.2.4. The optimum anneal temperature required to minimize contact resistance increases with decreasing Ge content from eutectic (12wt %) to off-eutectic (2.7 wt %) alloy. The data for anneal temperatures and durations optimized for lowest contact resistance, contact resistance for three alloy compositions, for Ni layer thickness of 30nm are summarized in table 4.2.2.

![Figure 4.2.4 Contact resistance ($R_{TC}$) vs. anneal durations ($t_a$) for eutectic and off-eutectic alloys.](image)

Table 4.2.2 Magnetic-to-non magnetic transition temperatures, surface roughness, contact resistance ($R_{TC}$), anneal temperature ($T_a$) and anneal duration ($t_a$) for three alloy compositions with different Ni layer thicknesses ($x_{Ni}$).

<table>
<thead>
<tr>
<th>AuGe alloy composition</th>
<th>Nickel layer thickness (nm)</th>
<th>Optimum anneal temperature ($T_a$) (°C)</th>
<th>Optimum anneal duration ($t_a$) (s)</th>
<th>Optimum contact resistance ($R_{TC}$) (Ω-mm)</th>
<th>Magnetic to non magnetic transition anneal temperature (°C)</th>
<th>Surface roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88:12</td>
<td>25</td>
<td>400</td>
<td>60</td>
<td>0.05±0.01</td>
<td>200-250</td>
<td>21±3</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>400</td>
<td>90</td>
<td>0.07±0.005</td>
<td>200-250</td>
<td>20.5±2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>400</td>
<td>150</td>
<td>0.90</td>
<td>250-300</td>
<td>11±1</td>
</tr>
<tr>
<td>95:5</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>250-300</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>400</td>
<td>90</td>
<td>0.17±0.02</td>
<td>250-300</td>
<td>5.5±0.5</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>350-400</td>
<td>-</td>
</tr>
<tr>
<td>97.3:2.7</td>
<td>30</td>
<td>430</td>
<td>120</td>
<td>1.30</td>
<td>400-430</td>
<td>4.5±0.5</td>
</tr>
</tbody>
</table>
The sheet resistance (which may include parallel resistances of multilayers) also can be derived from the contact resistance measurement by the TLM method, for the annealed samples. The sheet resistance increases marginally with anneal temperature and time (figure 4.2.5).

![Sheet resistance vs anneal durations](image)

**Figure 4.2.5** Sheet resistance ($R_s$) Vs anneal durations ($t_A$) for eutectic AuGe/Ni/Au.

### 4.2.3 Surface roughness

Atomic Force Microscope (AFM) images for eutectic AuGe(88:12)/Ni/Au, off-eutectic AuGe(95:5)/Ni/Au and AuGe (97.3:2.7)/Ni/Au deposited TLM pattern and annealed for durations that gave the lowest contact resistance are displayed in figure 4.2.6. The R.M.S. surface roughness computed over the scanned surface is given in table 4.2.2.

1. Off-eutectic alloy compositions give lower roughness but increased contact resistances.
2. The surface roughness is quite sensitive to Ni content, decreases steadily with increase of Ni layer thickness.
3. The surface roughness of eutectic AuGe/Ni/Au is $\sim$20.5 ±2 nm and off-eutectic alloy with AuGe (95:5)/Ni/Au is $\sim$5.5 ±0.5 nm and AuGe (97.3:2.7)/Ni/Au is $\sim$4.5 ±0.5 nm.
4. Increasing Ni layer thickness (50nm) above the optimum layer thickness increases the contact resistance $\sim 10$ times and reduces the roughness by 50%.

5. The use of the off-eutectic alloy with 95:5 wt % results in reduction of surface roughness by 75% and increases contact resistance about twice that of eutectic composition, albeit with a higher sensitivity to anneal temperature.

The use of AuGe (95:5wt %) alloy appears to be a good choice between the contradictory requirements of low surface roughness and low contact resistance, than increasing Ni layer thickness above that of samples which give the least contact resistance.

Figure 4.2.6 AFM micrographs of the surface of samples with (a) AuGe (88:12)/Ni(30nm)/Au(200nm), (b) AuGe(95:5)/Ni(30nm)/Au(200nm), (c) AuGe(97.3:2.7)/Ni(30nm)/Au(200nm) and annealed for durations that gave the lowest $R_{TC}$. 
4.2.4 Magnetic properties

The magnetic hysteresis loops recorded on AuGe (88:12, 95:5, and 97.3:2.7)-100 nm/Ni-30 nm/Au-100 nm for various annealing temperatures are shown in figure 4.2.7.

1. The data show that, while hysteresis loops of the as-deposited film structure are ferromagnetic, the loops become progressively less magnetic after being subjected to anneal at increasing temperatures.

2. The anneal temperature for which the structure becomes completely non-magnetic, increases with decreasing Ge content in the alloy (table 4.2.2).

![Magnetization hysteresis loops for AuGe (88:12)/Ni/Au, AuGe (95:5)/Ni/Au and AuGe (97.3:2.7)/Ni/Au annealed at various anneal temperatures.](image)

Magnetization hysteresis loops of annealed samples collapse as the anneal temperature is increased. The magnetization at 5 kG, as a percentage of that of the unannealed sample, is shown in figure 4.2.8, as anneal temperature is increased from 100
to 430°C. The results indicate that, the hysteresis loops of the as-deposited film structure are magnetic; the metallization structure becomes completely non-magnetic on annealing at or above a temperature which varies from 250°C to 430°C, as the Ge content is decreased and with increasing Ni-layer thickness (table 4.2.2). Hence, under conditions normally used for obtaining Ohmic contacts, the structure is non-magnetic for a wide range of Ni layer thicknesses. Notably, decrease in magnetization occur even at anneal temperatures as low as 100°C. The minimum anneal temperature required to complete the transformation to a non-magnetic phase is unknown, but lies in the range given in the shaded region.

![Figure 4.2.8](image.png)

**Figure 4.2.8** Anneal temperature ($T_A$) dependence of the fractional saturation magnetization for samples with three AuGe alloy compositions and two Ni layer thicknesses on GaAs multi-layer. $M_{s0}$ is the saturation magnetization of the un-annealed sample at 5 kG.

### 4.2.5 Differential Scanning Calorimetry (DSC)

DSC scans obtained for three AuGe alloy compositions (88:12, 95:5, 97.3:2.7 wt %) with a fixed (30nm) Ni layer thickness is shown in figure 4.2.9. Signatures of melting in the metallization structure occur at higher temperatures when Ge content is reduced.
Chapter 4  

AuGe/Ni/Au based Ohmic contacts

The AFM micrographs (figure 4.2.6) of the surface of two samples, one prepared with AuGe at the eutectic composition and the other with off-eutectic composition (95:5 wt %) both annealed at 400°C (at which the contact resistance is close to optimum) show a considerably reduced roughness (table 2) is evident in the latter sample whose anneal temperature is closer to the temperature of ‘melting’ in its metallization structure. Precise quantitative comparisons of temperatures are difficult in view of differences in experimental setup for the DSC and contact anneals, and also the rapid heating rates.

4.2.6 Structural Properties

The X-Ray diffractrogram of the AuGe (88:12 wt %) (100nm)/Ni (30nm)/Au (200nm) films deposited on GaAs/AlGaAs substrate and annealed at 400°C for 90s (optimum contact resistance) is shown in figure 4.2.10. Mainly peaks corresponding to GaAs/AlGaAs substrate and Au are detected in the as deposited un-annealed case.

At 400°C annealed sample the peaks corresponding to AuGa are also detected. The information regarding the inter layers could not be detected, in the either case, as the data was not from grazing incidence XRD.
Temperature dependence (4-300K) of the contact resistance is undertaken to study the changes in the electrical conductivity through the Ohmic contacts and also in the context of low-temperature applications of the magnetic field sensor [22]. The TLM measurements for contact resistances are carried out between 4K and 300K, at a number of different temperatures on three samples. One was a sample with the eutectic AuGe layer, namely AuGe (88:12 wt%)/Ni (30nm)/Au whose contact resistance is close to the optimum. The other two samples were those in which the roughness was reduced: one by increasing the Ni-layer thickness to 50nm and the other by using a AuGe layer composition of 95:5 wt%. The current–voltage (I-V) characteristics between the TLM pads at a gap spacing 25um at several different temperatures for AuGe (95:5)-100nm/Ni-30nm/Au-200nm are given in figure 4.2.11. The I-V curves are linear for all temperatures (300-4K).

**Figure 4.2.10** XRD analysis of AuGe-100nm/Ni-25nm/Au-200nm annealed at 400°C for 60s.
Figure 4.2.11 Current–voltage (I-V) characteristics at different temperatures.

Figure 4.2.12 Total resistance plotted as a function of contact separation at a number of different temperatures.

The total measured resistance $R_T$ plotted as a function of contact separation at different temperatures is shown in the figure 4.2.12, which is then extrapolated to zero to calculate $R_C$, $R_s$ and $L_T$ as explained in Chapter 1 & 2. The inset shows the total resistance as a function of temperature in the temperature range from 4K to 300K. The
slope and intercept of each line are obtained from the best fits to the data to obtain the sheet resistance $R_s$ and contact resistance $R_c$. The temperature dependence of contact resistance and sheet resistance are plotted in figures 4.2.13 and 4.2.14. The error is calculated by taking the R.M.S deviation at each temperature (details as in chapter 2).

**Figure 4.2.13** Total contact resistance $R_c$ plotted as a function of temperature.

**Figure 4.2.13** Measured sheet resistance $R_s$ plotted as a function of temperature.
The contact resistance increases, and the sheet resistance decreases as the measured temperature is decreased from 300K to 4K (figure 4.2.14 and 4.2.15). The contact resistance, $R_C$, is related to specific contact resistance $\rho_c$ and the contacted material sheet resistance, $R_s$, via the concept of transfer length, $L_T$. The transfer length characterizes the exponential decrease of current density in a direction perpendicular to the edge of the contact where the current crowding takes place and is given by [23].

$$L_T = \sqrt{\frac{\rho_c}{R_s}}$$

Temperature dependence (4-300K) of the contact resistance was undertaken on three samples to study the changes in the electrical contact mechanism and also in the context of low-temperature applications. One was a sample with the eutectic AuGe layer, namely AuGe (88:12 wt %)/Ni (30nm)/Au whose contact resistance is close to the optimum. The other two samples are those in which the roughness is reduced- one by increasing the Ni-layer thickness to 50nm and the other by using an AuGe layer composition of 95:5 wt%. The specific contact resistivity ($\rho_c$) of these samples as a function of temperature (4-300K) for AuGe (88:12)/Ni/Au with two Ni layer thicknesses (30 and 50nm) and AuGe (95:5)/Ni-30nm/Au are shown in figure 4.2.15.

![Figure 4.2.15](image)

**Figure 4.2.15** Specific contact resistance $\rho_c$ plotted as a function of inverse temperature for three AuGe alloy compositions with different $x_{Ni}$. 

$$\rho_c = C \exp \left[ \frac{\phi_B}{E_\infty \coth \frac{E_\infty}{k_B T}} \right]$$
The contact resistivity increases, as the measured temperature is decreased from 300K to 4K (table 4.2.3). The experimental data have been fitted using the expressions of ρc based on the thermionic and tunneling models of current transport through the metal semiconductor contacts [25, 26] (chapter 1, section 1.2). The graph also shows the fitted curve to the equation based on the thermionic field emission.

\[ \rho_c = C \exp \left[ \frac{\phi_B}{E_{oo} \coth \frac{E_{oo}}{k_B T}} \right] \]

The specific contact resistance in this case depends on temperature and transmission co-efficient of tunneling \( E_{oo} \). \( \phi_B \) is the barrier height. The value of \( E_{oo}/k_B \) is the measure of the temperature below which electronic conduction is tunneling dominated and independent of temperature.

Table 4.2.3 shows the temperature dependence of contact resistivity and the value of barrier height, tunneling parameter etc. We observe that

1. The contact resistance shows strong temperature dependence, in the range (4-300K), with indications of both thermionic and tunneling behaviours.
2. \( \rho_c \) decreases with increase of temperature. Figure 4.2.15 shows that the logarithm of \( \rho_c \) increases nearly linearly with \( 1000/T \) over temperature range 4K to about 100K and levels off as the temperature decreases to below 100K.
3. The Arrhenius behaviour shown in figure 4.2.16 indicates the presence of a potential barrier and presence of thermionic current transport above 100K.
4. The weak temperature dependence of \( \rho_c \) below 100K indicates a change in the current transport mechanism from thermionic to tunneling.
5. The barrier height for current conduction increases relative to the samples with the eutectic AuGe layer, for increase of Ni and decrease in Ge contents in structure; the increase is less in the latter case relative to the former.

<table>
<thead>
<tr>
<th></th>
<th>Specific contact resistance (Ω-cm²)</th>
<th>( \phi_B ) (meV)</th>
<th>( E_{oo} ) (meV)</th>
<th>( E_{oo}/k_B ) (K)</th>
<th>log C</th>
</tr>
</thead>
<tbody>
<tr>
<td>AuGe(88:12)/Ni-30/Au</td>
<td>1x10⁻⁶</td>
<td>4.5x10⁻⁵</td>
<td>1.7x10⁻⁴</td>
<td>31±0.5</td>
<td>10.3±0.1</td>
</tr>
<tr>
<td>AuGe(88:12)/Ni-50/Au</td>
<td>1x10⁻⁶</td>
<td>1.8x10⁻⁴</td>
<td>2.7x10⁻⁴</td>
<td>38±0.7</td>
<td>13.1±0.1</td>
</tr>
<tr>
<td>AuGe(95:05)/Ni-30/Au</td>
<td>3.2x10⁻⁶</td>
<td>7.6x10⁻⁵</td>
<td>2.4x10⁻⁴</td>
<td>34.5±1</td>
<td>11±0.15</td>
</tr>
</tbody>
</table>

Table 4.2.3 Temperature dependent contact resistivity for two alloy compositions with different Ni layer thicknesses (\( x_{Ni} \)).
At $T = 0$, $\rho_c \to \infty$, the carriers get localized as they do not have sufficient energy to overcome the barrier.

The enhancement in amount of Ni-Ge compounds formed with increasing Ni layer thicknesses, and less Ge in-diffusion into GaAs with decrease of Ge content in the alloy could be the cause for increase in barrier height with increase of Ni layer thickness and decrease of Ge content in the AuGe alloy.

4.3 Conclusions

1. The eutectic AuGe (88:12 wt% alloy)-100nm/Ni-30nm/Au-200nm, gives the lowest contact resistance of $0.07 \pm 0.005 \, \Omega\cdot\text{mm}$, of various AuGe compositions (Ge content).
2. Decreasing the Ge content in the alloy from the eutectic increases the contact resistance.
3. The off-eutectic AuGe (95:5 wt%)-100nm/Ni-30 nm/Au-200nm configuration gives contact resistance of $\sim 0.17 \pm 0.02 \, \Omega\cdot\text{mm}$ and AuGe (97.3:2.7 wt%)-100nm/Ni-30nm/Au-200nm gives contact resistance $\sim 1.3 \, \Omega\cdot\text{mm}$.
4. Off-eutectic alloy compositions give lower roughness but increased contact resistances.
5. The surface roughness is quite sensitive to Ge content, decreases steadily with decrease of Ge content.
6. The off eutectic alloy AuGe (95:5) with optimum Ni layer thickness appear to be a good choice between surface roughness and contact resistance than increasing Ni layer thickness above the optimum in the eutectic alloy.
7. The metallization structures are rendered non-magnetic at room temperature after annealing at typically used alloying conditions of temperature (400-430°C).
8. Conversion of Ni to non-magnetic phases, begins at anneal temperatures as low as 100°C and is completed at an anneal temperature that increases with decreasing Ge content in the AuGe alloy (250-430°C).
9. Signatures of melting are seen in Differential Scanning Calorimetry; indicate that the melting temperature increases with decreasing Ge content.
10. Increasing Ni layer thickness increases metallization melting temperature and reduces surface roughness.

11. The structural studies show phases corresponding to Au and substrate in the as deposited case and in the annealed samples formation of AuGa phase is also detected.

12. Low temperature contact resistance measurements indicate that carrier conduction at the contacts have characteristics of both tunneling and thermionic emission.

13. The barrier height increases for samples with increased Ni layer thickness and decreased Ge content in the alloy.
References


