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Rapid thermal annealing of Zr/SiGeC contacts

M. Barthula[a,] *, V. Aubry-Fortuna[a], F. Meyer[a], O. Chaix-Pluchery[b],
A. Eyal[c], M. Eizenberg[c], P. Warren[d]

[a]*Institut d'Electronique Fondamentale, CNRS URA 22, Bât. 220, Université Paris Sud, 91405 Orsay Cedex, France*
[b]*LMGP, CNRS UMR 5628, ENSPG, BP75, 38402 St. Martin d'Hères, France*
[c]*Solid-State Institute, Technion, Haifa 32000, Israel*
[d]*Institute for Micro- and Optoelectronics, Swiss Federal Institute of Technology, 1015 Lausanne, Switzerland*

Abstract

In this work, the effect of rapid thermal annealing (400–800°C, 5 min) on the electrical properties of Zr/$Si_{1-x-y}Ge_xC_y$ contacts was investigated. Previously, we have shown that the reaction of Zr with SiGeC leads to the final compound C49-$Zr(Si_{1-z}Ge_z)_2$, with $z = x$ for all compositions examined and that no Ge-segregation is detected. After the reaction, only a small strain relaxation is observed in the unreacted SiGe epilayer, while the strain is totally preserved in the SiGeC one. Schottky barrier heights have been studied as a function of the annealing temperature. RTA leads to a decrease of the barrier for both n- and p-type. The decrease of the barrier height with reverse voltage is always well described by the thermionic emission. Nevertheless, the slight increase of the standard deviation, deducted from barrier height histograms, may show that few interface defects are created during annealing. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Lately, there has been a growing interest in SiGe alloys for applications in electronic devices such as heterojunction bipolar transistors (HBT) and modulation-doped field effect transistor (ModFET). However, the 4.2% lattice mismatch between Si and Ge imposes severe restrictions in terms of critical thickness and thermal stability. Adding C to $Si_{1-x}Ge_x$ provides additional parameters in strain control [1, 2] and bandgap engineering [3]. The fabrication of reliable ohmic and rectifying contacts is a critical step for new IV–IV heterostructure devices and requires a good control of electrical properties and thermal stability. Indeed, these structures are sensitive to any high-temperature treatment, which can lead to strain relaxation and (or) dopant diffusion. This results in an unacceptable degradation of the device performances. Some experiments have been carried out to study the reaction of SiGe with Ti [4–6], Pd [7], W [8], Co [6, 9, 10] and other metals. The thermal treatments are usually performed with conventional annealing either under ultra high vacuum (UHV) [4, 5, 7] or under an atmosphere of inert gas [9]. Strain relaxation [5] of the epilayer and Ge-segregation [4, 5, 7, 9] mostly occur during such thermal treatments. One way to prevent these detrimental effects is to reduce the thermal budget by using rapid thermal annealings (RTA) [6, 8, 10]. RTA is a convenient technology for production which also allows a good control of the reaction environment. Nevertheless, in the case of the Ti/SiGe system, Aldrich et al. [4] have shown that RTA only leads to a reduction of Ge-segregation but does not prevent it totally, and a dramatic strain relaxation has been reported after Co/SiGe reaction performed in a RTA system [6, 10]. Therefore, it is also important to choose a metal which in principle avoids Ge-segregation. Recently, the Nemanich group [11] has proposed a new attractive system with Zr as a metal. Their experimental results showed that the system Zr/SiGe is more stable to Ge-segregation than the Ti/SiGe one,

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* Corresponding author.

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even after an annealing at 700°C for 100 min. In previous articles, we have investigated the thermal stability of the Zr/$Si_{1-x}Ge_x$ system using RTA at temperatures ranging from 400 to 800°C [12, 13]. The XRD analyses have indicated that C49-Zr$(Si_{1-y}Ge_y)_2$ with $y = x$ was the final phase of the Zr/$Si_{1-x}Ge_x$ reaction, regardless of the initial $Si_{1-x}Ge_x$ alloy compositions ($0.1 \leq x \leq 0.33$). At 600°C, the reaction forming the orthorhombic Zr$(Si_{1-y}Ge_y)$ has begun and the formation of C49-Zr$(Si_{1-y}Ge_y)_2$ is initiated. At 800°C, the phase C49-Zr$(Si_{1-y}Ge_y)_2$ is not always completely achieved, some Zr$(Si_{1-y}Ge_y)$ peaks can be still detected. According to XRD, RBS and EDS measurements, no Ge-segregation has occurred during the reaction. The TEM images confirm that no Ge-excess is detected at the interface, at the surface, nor at the grain boundaries. No modification of the reaction was observed due to C-incorporation. In addition, FCD analyses were performed to follow the state of strain of the unreacted epilayer [13]. A small strain relaxation has only occurred in the unreacted SiGe epilayer during the reaction, while the strain is totally preserved in the SiGeC one. All these results lead to the conclusion that Zr offers the possibility to realize stable contacts, in terms of Ge-segregation and strain relaxation.

In this work, in order to investigate further the potentiality of Zr/SiGe(C) contacts, we have focused on its electrical properties, after annealing in a RTA furnace at a temperature ranging from 600 to 800°C for 5 min. We will report changes in the Schottky Barrier Height (SBH) on n-type and p-type SiGeC layers due to different annealing conditions.

2. Experimental procedures

The samples used consisted of p-type (B doped) and n-type (P doped) relaxed and pseudomorphic $Si_{1-x-y}Ge_xC_y$ layers (x = 0.10–0.17 and y = 0.005–0.013). The 100 nm-SiGeC layers were grown by rapid thermal chemical vapor deposition on a (100) oriented Si substrate of the same type at 550–570°C. Prior to metal deposition, each SiGe sample was cleaned using the same procedure: a standard chemical degreasing was followed by a dip in diluted HF for 30 s and a final rinsing in deionised water. 16–80 nm-Zr films were deposited in a dc-magnetron sputtering chamber. Photolithography followed by a photoresist annealing at 150°C and a selective etch were used to define 96 diodes of different areas (0.071–0.384 mm^2). Heat treatments only concerned the 16 nm-Zr film and were performed in a RTA system under Ar/H_2 atmosphere at a temperature from 600 to 800°C for 5 min. The thickness of Zr films was chosen so that the Zr/SiGe reaction would not completely consume the SiGe layer. During annealing, the sample was maintained between two other samples of Zr/Si. In this case, the sample surface was protected and was not directly in contact with the furnace atmosphere. This procedure limits oxidation in an acceptable range. The Schottky barrier height (SBH) values Φ_b were determined by the I–V measurement of the reverse current at room temperature. To improve the resolution, at least 30 diodes were systematically characterized in order to obtain a mean SBH value with good accuracy and informations on the homogeneity of the interface. More details of this procedure can be found in Ref. [14].

3. Results and discussion

Fig. 1 exhibits the SBH as a function of the annealing temperature for both Zr/p-$Si_{0.83}Ge_{0.17}$ and Zr/n-$Si_{0.84}Ge_{0.16}$ contacts. For p-type, the RTA treatment mostly leads to a decrease of the SBH. For n-type, the SBH first increases up to 600°C and then decreases. After a reaction at 800°C, Φ_{bp} and Φ_{bn} always exhibit lower values than those before annealing. In principle, according to the theory of barrier formation developed by Schottky, the sum $\Phi_{bp} + \Phi_{bn}$ is expected to give the band-gap of the semiconductor E_g [15]. Indeed, we have shown that this model describes rather well our results on as-deposited samples [14]. After RTA at 800°C, the slight strain relaxation of the SiGe underlayer should lead to an increase of E_g and cannot explain the decrease of both Φ_{bp} and Φ_{bn}. Therefore, the SBH lowerings are likely due to the formation of zirconium germanosilicide and interface defects even if no Ge-segregation was evidenced by TEM. In order to better understand our results, we have analyzed the SBH values, for samples as-deposited and annealed at 800°C.

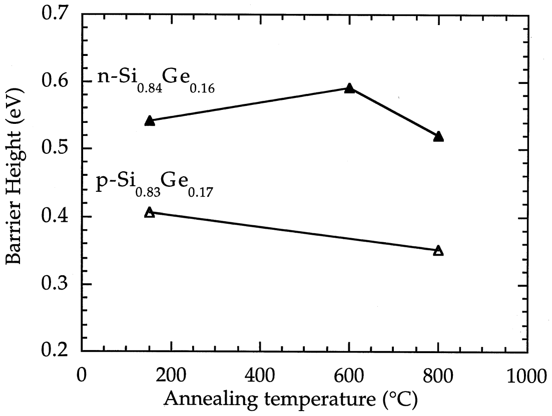

Fig. 1. Schottky barrier height values as a function of the annealing temperature for Zr/p-$Si_{0.83}Ge_{0.17}$ and Zr/n-$Si_{0.84}Ge_{0.16}$ contacts.

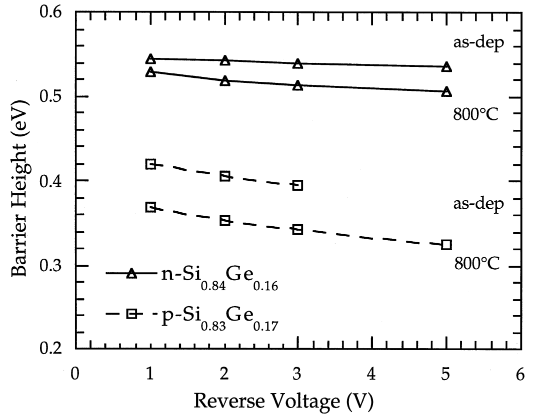

Fig. 2. Variations of the Schottky barrier heights as a function of the reverse voltage for Zr/p-$Si_{0.83}Ge_{0.17}$ and Zr/n-$Si_{0.84}Ge_{0.16}$ contacts.

The variations of SBHs as a function of the reverse voltage have been studied for both Zr/p-$Si_{0.83}Ge_{0.17}$ and Zr/n-$Si_{0.84}Ge_{0.16}$ contacts (Fig. 2). The decrease of SBH with voltage, before and after annealing, is well described by the thermionic emission, taking into account the same image force lowering and field effect through an interfacial layer. This shows that the conduction mode is conserved and that the degradation of the interface, if it exists, is limited.

Fig. 3 shows typical SBH histograms of Zr/n-$Si_{0.84}Ge_{0.16}$ diodes obtained from reverse current measured at 2 V on samples as-deposited and annealed at 800°C. The standard deviation of SBH increases with the temperature from 1.5 to 7.5 meV. The soft scattering in SBH, before annealing, accounts for a very homogeneous metal/semiconductor (M/SC) interface on the whole surface of the sample. The slight increase of the standard deviation, after thermal treatment, suggests that some degradation has occurred at the interface M/SC and may show some inhomogeneities at the interface. Nevertheless, it is noteworthy that the value of the standard deviation after annealing remains small. We have also investigated the influence of the annealing on the Zr/p-$Si_{0.83}Ge_{0.17}$ contact. An increase of the standard deviation from 1.9 to 4.1 meV is observed. The same trends with annealing are observed for p-type and n-type and may show a slight reduction of the quality of the interface.

4. Conclusions

In conclusion, the C49-$Zr(Si_{1-z}Ge_z)_2$ compound is formed after severe annealing conditions (800°C, 5 min) of Zr/$Si_{1-x-y}Ge_xC_y$ contact and no Ge-segregation is observed. The reaction only leads to a slight strain relaxation in the SiGe epilayer. The presence of carbon still improves the stability of the system and no relaxation occurs in the unreacted layer. We have also shown that for Zr contacts on both p-type and n-type SiGe(C) layers, the thermionic mode is preserved after annealing. We have observed that whatever the type there is a decrease of the SBH after the annealing at 800°C and a slight increase of the SBH standard deviation. These last results suggest that few interface defects are created during annealing. To understand

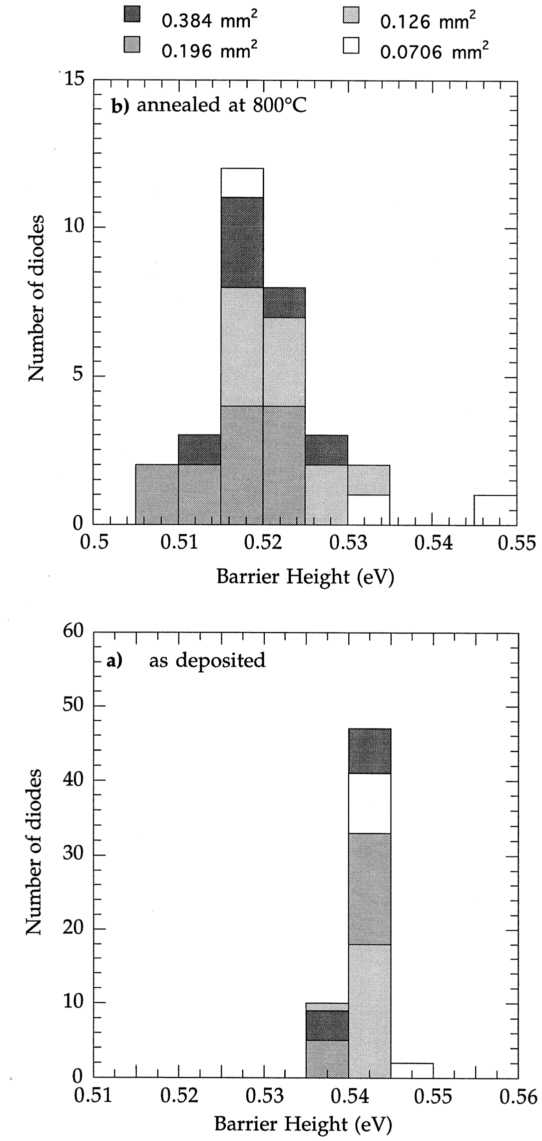

Fig. 3. Histograms of Schottky barrier heights of Zr/n-$Si_{0.84}Ge_{0.16}$ with areas varying from 0.071 to 0.384 mm^2: (a) as-deposited and (b) after annealing at 800°C. The histograms are obtained from reverse current measured at −2 V.

the decrease of the sum $\Phi_{bp}+\Phi_{bn}$, further investigations are required.

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