CHAPTER 5: RESULTS

Morphological evolution of metal Schottky contacts on n-Ge (100)

5.1 Introduction

As device dimensions are scaled to submicrometer dimensions in silicon-based microelectronics, new processes and materials are becoming necessary to overcome the limitations of the conventional methods [1]. Of interest are silicon compatible materials that provide better device performance. Germanium (Ge) is a promising material for high mobility devices due to its higher and more symmetric carrier mobility compared with silicon [2], and its excellent compatibility with high-k materials [3]. Metal germanides may be used as contact materials in future germanium technology. Compared with silicides that have been extensively investigated in the past [3,4], formation of germanides on single crystal germanium surface attracted less attention. However, most of the studies on germanide formation up to date have been carried out using in-situ annealing by slowly-ramping annealing temperature or rapid thermal annealing processing (RTP), rather than using furnace annealing, and also with less emphasis on morphological evolution [5]. In this study, we investigated the evolution and microstructure stability of metal (Pt, Ni, Ti, Ir, and Ru) films on n-Ge (100) after furnace annealing.

5.2 Experimental procedures

Ge (100) n-type substrates were used in this study. The substrates were first degreased and subsequently etched in a mixture of H_2O_2 (30%): H_2O (1:5) for 1 min. Metal films of 30 nm were deposited by electron beam or resistive evaporation with base pressure less than 10^{-6} Torr. The metal layer thickness and deposition rates were monitored with a quartz crystal thickness monitor. The metal films were isochronally annealed in an oven under flowing Ar ambient in the temperature range 25-800°C for 30 min.

The characterization of the films for as-deposited and after different annealing temperatures was accomplished using a JEOLJSM-5800LV and a ZEISS ULTRA PLUS scanning electron microscopy (SEM) systems operating at 5 kV and 1 kV, respectively.

5.3 Results and Discussion

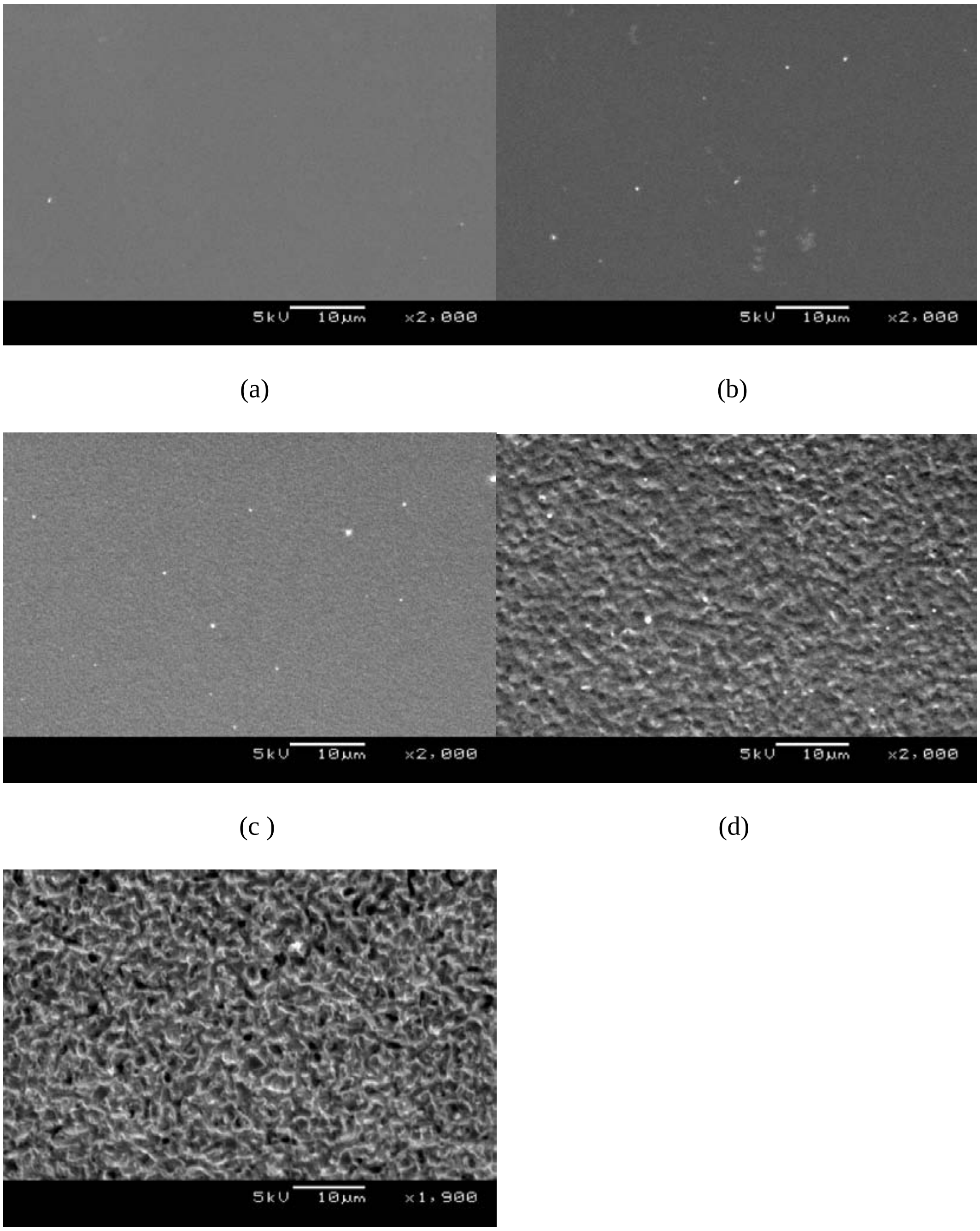
In this section results on the morphological evolution and microstructure stability of metal (Pt, Ni, Ti, Ir, Ru) films on n-Ge (100) using furnace annealing are presented.

5.3.1 Morphological evolution of Pt films on n-Ge (100)

Scanning electron microscopy (SEM) observations were conducted for Pt/n-Ge (100) samples, as-deposited and after annealing at different temperatures. The morphological evolution of Pt/n-Ge (100) is shown in Fig. 5.1. As shown in Fig. 5.1 (a), (b) and (c), metal surfaces show little change when samples were annealed below 600°C. This is in agreement with what was reported by Yao et al. [6] that the Pt-germanide exhibited no sign of agglomeration even up to 500°C anneal, suggesting good morphological stability for Pt-germanide films. Onset of surface roughening occurs at 500 °C. At 600°C anneal and above (see Fig. 5.1 (d-e)), the surface becomes rough, indicating the agglomeration of Pt, finally destroying the contact, as evidenced by the loss of rectifying properties of the Pt Schottky contacts after 600°C anneal (reported in Chapter 4, section 4.3.1). From the results, it can be concluded that the onset temperature for agglomeration in the 30 nm Pt/Ge (100) system occurs at 600 – 700°C.

5.3.2 Morphological evolution of Ni films on n-Ge (100)

Fig. 5.2 shows the evolution of surface morphology for Ni/n-Ge (100) with annealing temperature. Although Lee et al. [5] and Zhang et al. [7] have reported grain growth and groove deepening at the surface after a 400°C anneal for Ni film thickness of 15 nm, with Yao et al. [6] reporting the development of severe grain boundary grooving after 500°C anneal (onset temperature for 15 nm Ni film agglomeration), prominent grain growth at the surface of 30 nm layer (see Fig. 5.2 (c)) were evident from 500°C, indicating inception of agglomeration.



(a) (b)

(c) (d)

(e)

Fig. 5.1 *SEM observation for Pt films deposited on germanium after isochronal thermal treatment for 30 min at different annealing temperatures: (a) as-deposited, (b) 400°C, (c) 500°C, (d) 600°C and (e) 700°C*

Agglomeration starts with grain boundary grooving and progresses to island formation [5]. After a 600°C anneal, we observed development of severe grain grooving. The temperature at which grain growth and agglomeration occurs decreases with reduced film thickness [4]. This is consistent with the grooving model for agglomeration [4], as in our study the metal film thickness was 30 nm. We also observed that after 700°C (see Fig. 5.2 (e)), film continuity was severely interrupted as indicated by dark spots caused by exposed Ge regions. The agglomeration is driven by the minimization of the total surface/interface energy of the metal-germanide and germanium substrate [8]. We have found that the onset of the agglomeration process for 30 nm Ni/n-Ge(100) system to be in 500 – 600°C.

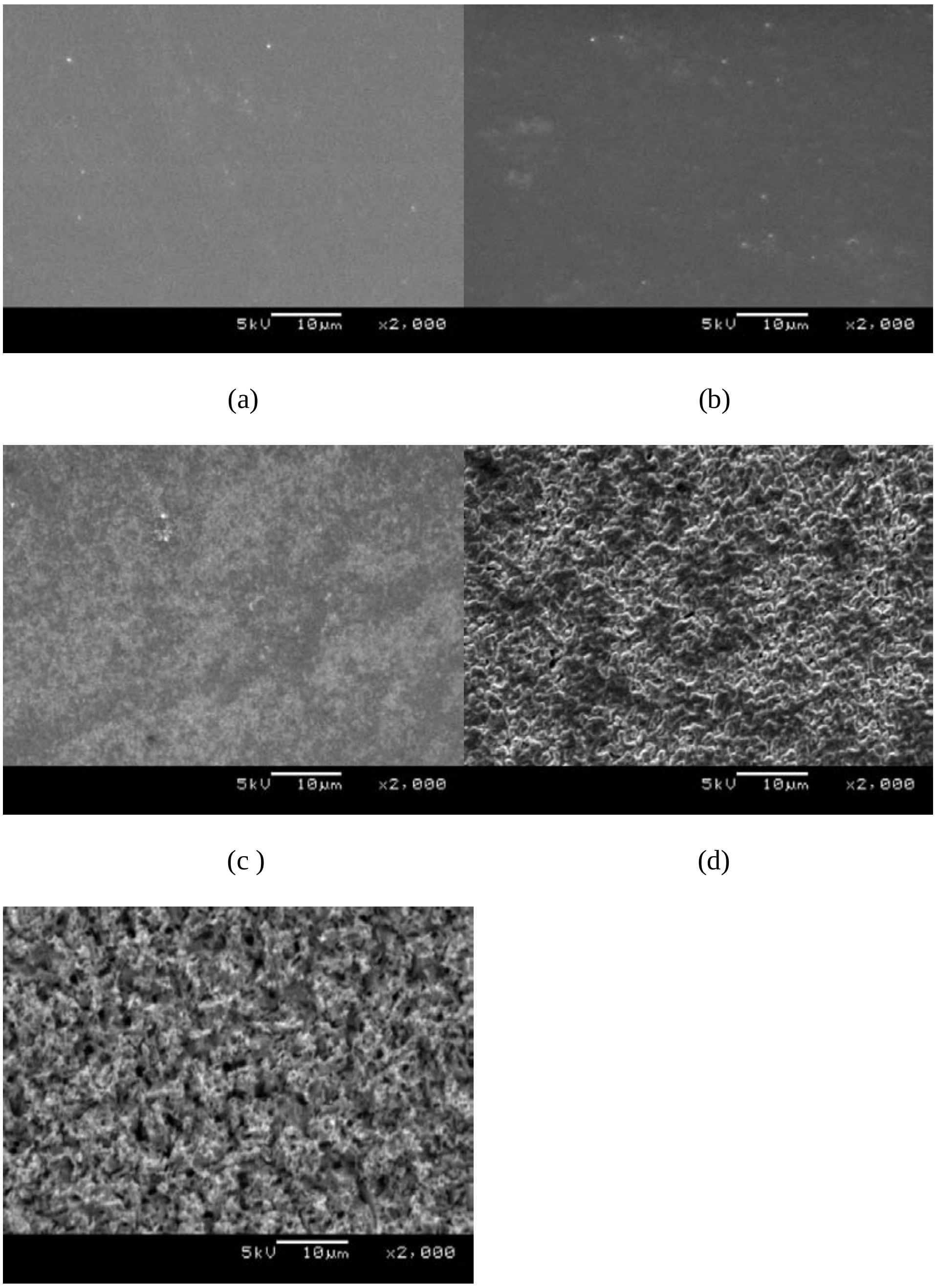
5.3.3 Morphological evolution of Ti films on n-Ge (100)

Fig 5.3 shows the SEM images of Ti/n-Ge (100) films at different annealing temperatures. Although Ti/Schottky contacts lost their rectifying behaviour after 425°C anneal, the metal surface shows no change when the sample was annealed below 600°C. Grain growth and grove deepening at the surface were evident from 700°C, suggesting better morphological stability than Pt and Ni films.

5.3.4 Morphological evolution of Ir films on n-Ge (100)

SEM observations of the Ir/n-Ge (100) for as-deposited sample and morphological evolution of the samples after annealing at different temperatures are shown in Fig. 5.4. In Fig. 5.4 (a) and (b) the metal surface shows little change when annealed below 400°C. Grain growth at the surface (see Fig. 5.4 (c)) was evident after a 500°C anneal. From this we suggest a relatively good morphological stability for Ir germanide films. A severe grain grooving was observed after 600°C anneal (see Fig. 5.4 (d)). We also observed that after 700°C anneal (see Fig. 5.4 (e)), film continuity was severely interrupted due to grain growth.

From these observations we conclude that the onset of the agglomeration process for 30 nm Ir/n-Ge (100) system occurs at 600 – 700°C.

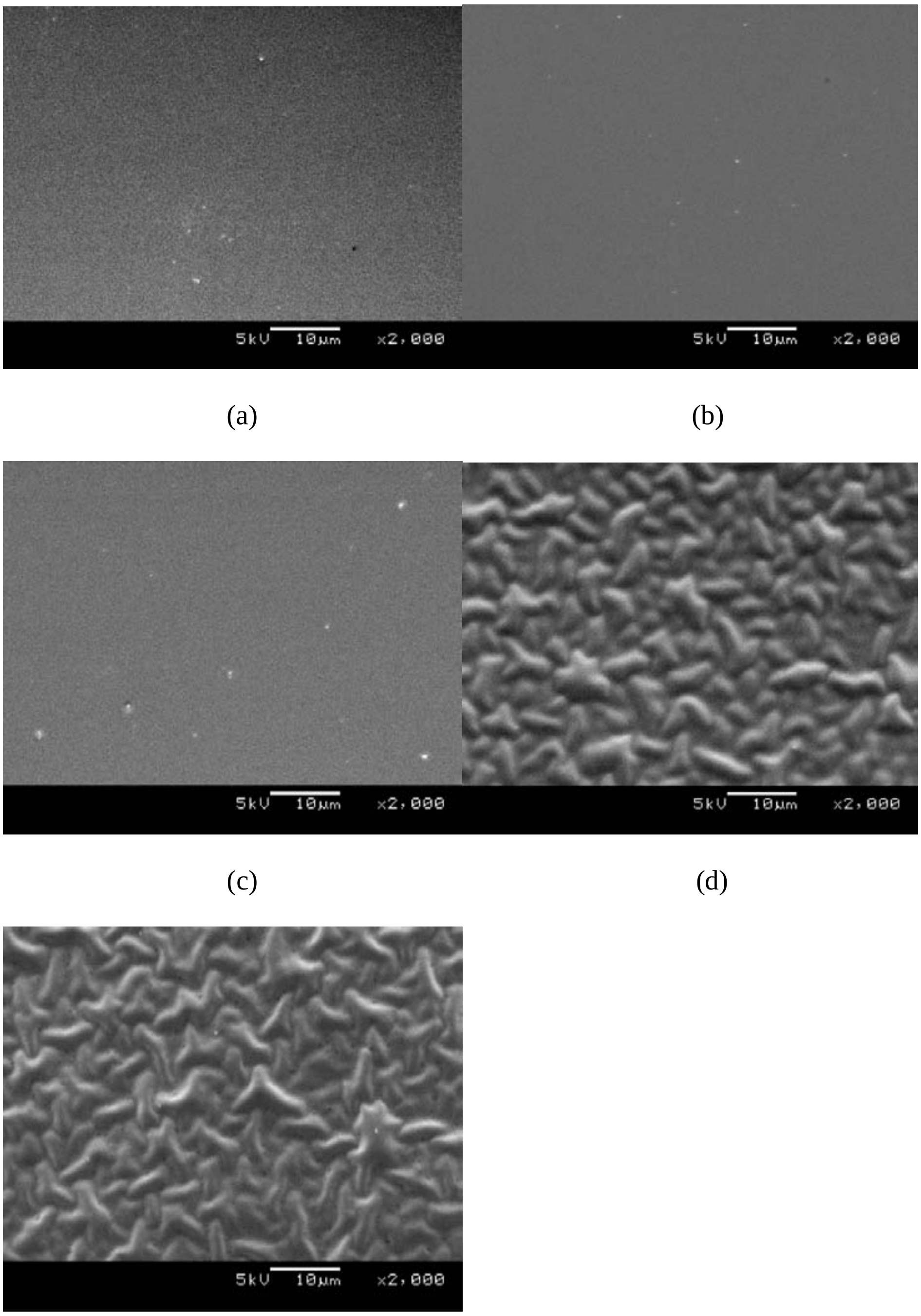


(a) (b)

(c) (d)

(e)

Fig. 5.2 *SEM observation for Ni films deposited on germanium after isochronal thermal treat for 30 min at different annealing temperatures: (a) as-deposited, (b) 400°C, (c) 500°C, (d) 600°C and (e) 700°C.*

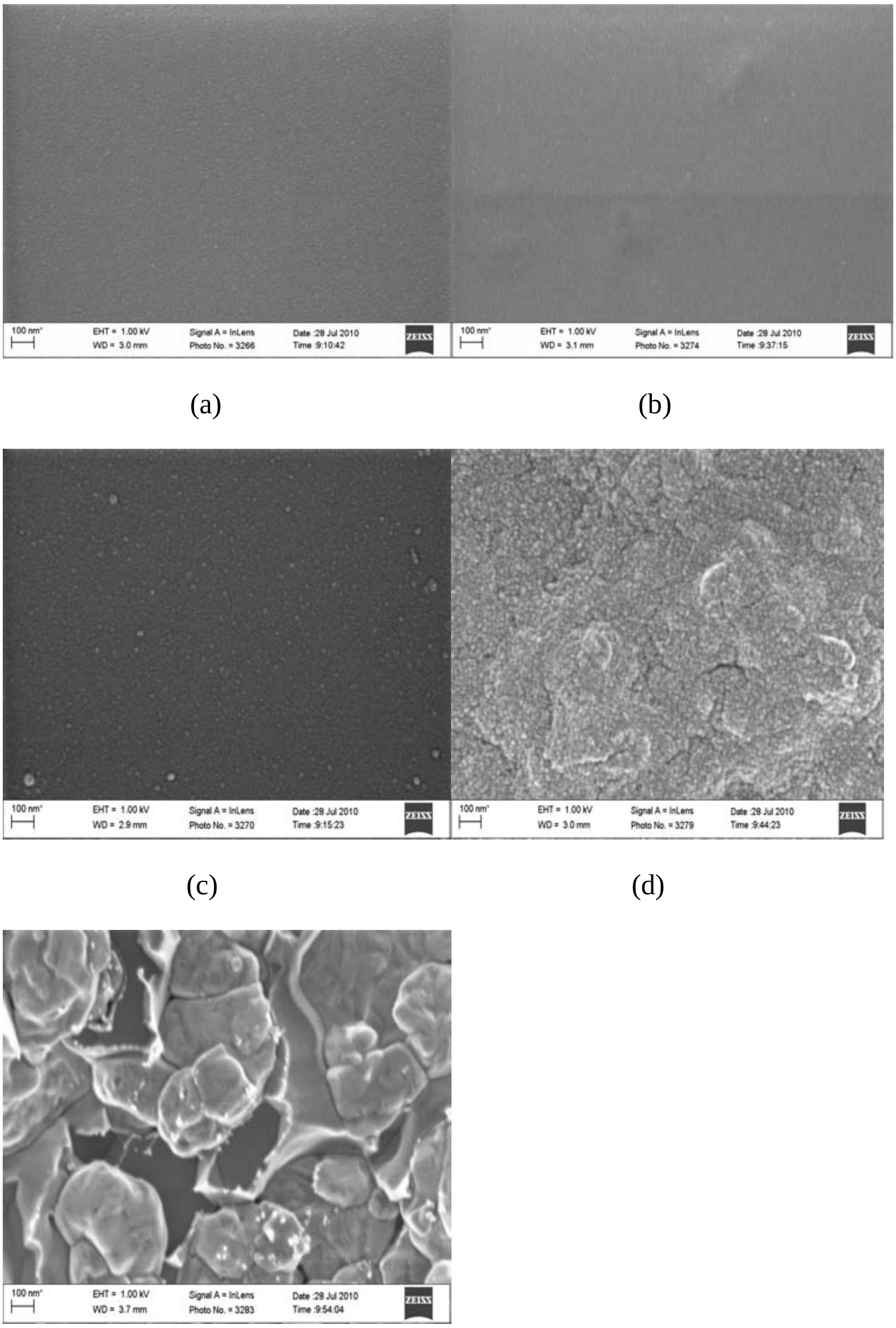


(a) (b)

(c) (d)

(e)

Fig. 5.3 *SEM observation for Ti films deposited on germanium after isochronal thermal treat for 30 min at different annealing temperatures: (a) as-deposited, (b) 500°C, (c) 600°C, (d) 700°C and (e) 800°C.*

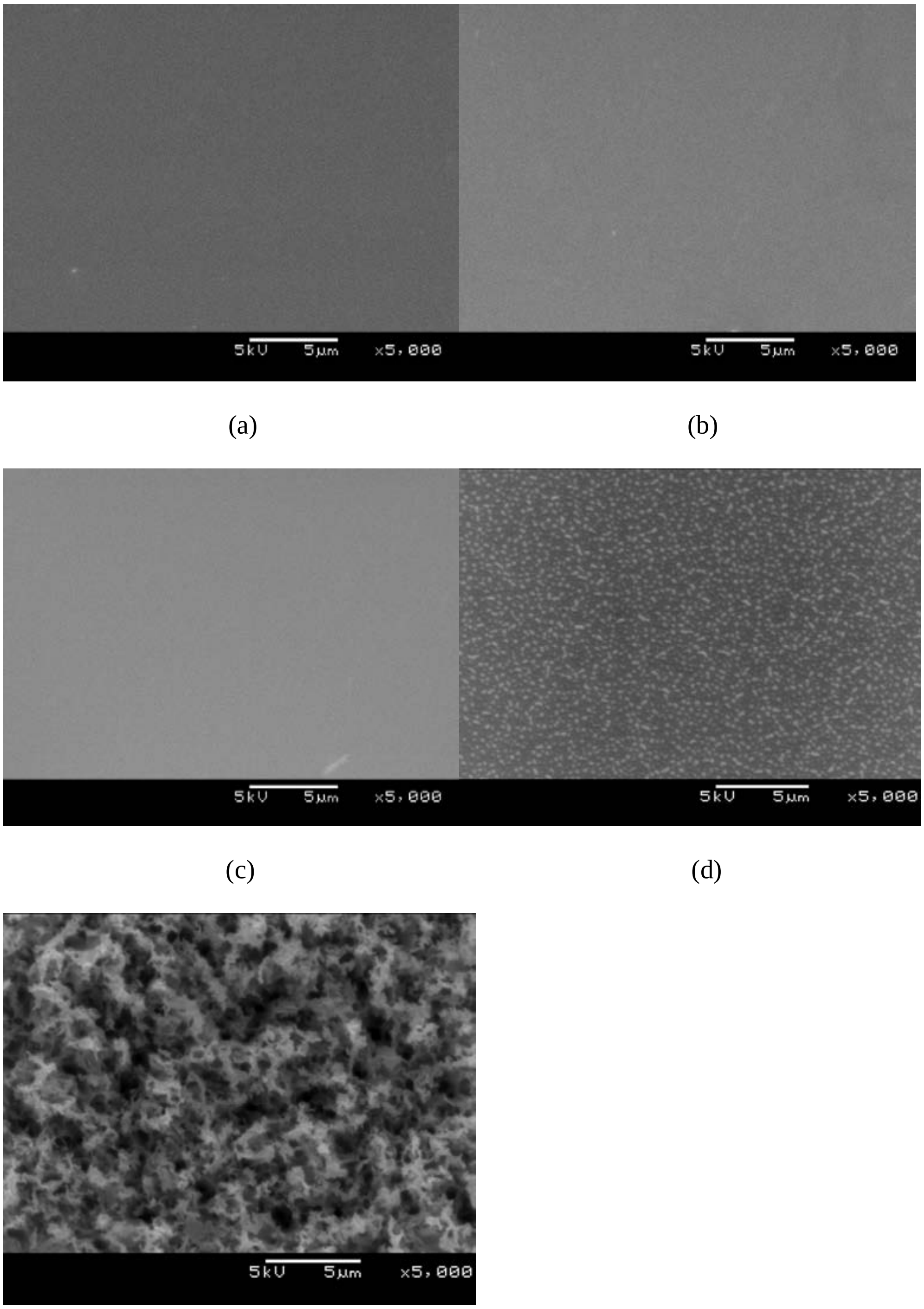


(a) (b)

(c) (d)

(e)

Fig. 5.4 *SEM observation for Ir films deposited on germanium after isochronal thermal treat for 30 min at different annealing temperatures: (a) as-deposited, (b) 400°C, (c) 500°C, (d) 600°C and (e) 700°C.*



(a) (b)

(c) (d)

(e)

Fig. 5.5 *SEM observation for Ru films deposited on germanium after isochronal thermal treat for 30 min at different annealing temperatures: (a) as-deposited, (b) 400°C, (c) 500°C, (d) 600°C and (e) 700°C.*

5.3.5 Morphological evolution of Ru films on n-Ge (100)

SEM observations of the Ru/n-Ge (100) for as-deposited and morphological evolution of the samples after annealing at different temperatures are shown in Fig. 5.5. In Fig. 5.5 (a), (b) and (c) the metal surface shows little change when annealed below 500°C. Grain growth at the surface was evident after a 600°C anneal (see Fig. 5.5 (d)). After annealing at 700°C (see Fig. 5.5 (e)), film continuity was interrupted as indicated by dark spots caused by exposed Ge regions. It can be concluded from the SEM micrographs that the onset of agglomeration in the Ru/n-Ge (100) system is at 600 – 700°C.

5.4 Summary and Conclusions

Pt, Ti, Ir, and Ru films were deposited by electron beam system, while Ni films were deposited by resistive evaporation on n-Ge. SEM observations were conducted for samples annealed at different temperatures. From SEM observations, it can be concluded that the onset temperature in 30 nm Ni/n-Ge (100), and Pt-, Ir- and Ru/n-Ge (100) systems occurs at 500 – 600 °C and 600 – 700°C, respectively. Grain growth at the surface of these metals was evident from 500°C, suggesting a better morphological stability.

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List of publications

1. A. Chawanda, C. Nyamhere, F.D. Auret, W. Mtangi, m. Diale, J.M. Nel, J. Alloys Compd. **492** (2010) 649.

2. J.M. Nel, A. Chawanda, F.D. Auret, W. Jordaan, R.Q. Odendaal, M. Hayes, S. Coelho, Physica B **404** (2009) 4493.