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ScienceDirect
Applied Surface Science 254 (2008) 4999–5006
applied surface science
www.elsevier.com/locate/apsusc

Electrode contact study for SiGe thin film operated at high temperature

Lionel Fabrice Houlet, Woosuck Shin *, Maiko Nishibori,
Noriya Izu, Toshio Itoh, Ichiro Matsubara

Advanced Manufacturing Research Institute, AIST, Shimo-Shidami, Moriyama-ku, Nagoya 463-8560, Japan

Received 26 December 2007; received in revised form 29 January 2008; accepted 29 January 2008
Available online 12 February 2008

Abstract

A study on the electrode contact of the sputtered SiGe thin film is reported for application of devices working at high temperature. Surface morphological characterization with optical microscope and AFM (atomic force microscope) together with the electrical characterization by TLM measurements (transmission line method) were performed before and after aging at 500 °C for 24 h using various sputtered multilayer electrodes, Ti/Au/Ti, Ta/Pt/Ta and Ti/Pt/Ti, on 300-nm B-doped SiGe thin film deposited by magnetron sputtering and furnace crystallisation at high temperature. After aging at 500 °C for 24 h, the Ti/Au/Ti multilayer electrodes seriously degraded to be non-ohmic contact, showing rough surface morphology. The Ti/Pt/Ti metal layers showed the lowest specific contact, resistivity before and after aging, $1.46 \times 10^{-3}\ \Omega\,\mathrm{cm}^2$ and $1.68 \times 10^{2}\ \Omega\,\mathrm{cm}^2$ respectively.

PACS : 73.40.NS; 68.55.J−; 68.60.Dv; 84.37.+q; 81.15.Cd

Keywords: SiGe; Sputtering; Electrode; Contact; TLM; High temperature; Specific contact resistivity; Adhesion layer

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1. Introduction

SiGe has attracted a lot of attention in research and development, as it can enhance the performance of electronic devices [1,2]. Epitaxial SiGe shows high electrical performance and various metal electrical contacts have been studied on SiGe grown by MBE (molecular beam epitaxy) and LPCVD (low-pressure chemical vapor deposition) techniques [3–5]. Epitaxial SiGe is the choice material for the semiconductor industry with high level of output and large budget. Alternatives to the MBE and LPCVD techniques are the deposit of SiGe by magnetron sputtering and furnace crystallisation at high temperature [6], and the epitaxial growth by ion-beam sputtering [7]. Sputtered SiGe thin film is an environmental friendly process (without dangerous nor toxic gas) and shows acceptable electrical properties in MEMS (micro electro mechanical systems) and electronic applications [6,8]. As many MEMS applications require working at rather high temperature, we propose here to study the metal electrode contacts on SiGe, prepared by magnetron sputtering and furnace crystallisation, for high temperature operation.

2. Experimental

The study of the metal/SiGe electrical contacts was performed using double side polished 350 μm n-type silicon wafers covered by a 250 nm-SiN/80 nm-SiO_2 multilayer on both side. After the deposit of 300 nm SiO_2 layer by a PECVD-TEOS (plasma enhanced chemical vapor deposition-tetraethylorthosilicate) technique and annealing at 600 °C for 2 h in air, the metals and boron doped $Si_{0.8}Ge_{0.2}$ (p-type) layers were deposited by dc magnetron sputtering (i-sputter, Ulvac). Three hundred nanometre of SiGe was deposited and annealed at 1000 °C for 5 h in Ar atmosphere prior to the simultaneous deposit of metal layers (see Fig. 1). Ti or Ta was used as an adhesion layer before and after the deposit of metal layer (Cu,

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* Corresponding author at: National Institute of Advanced Industrial Science and Technology (AIST), Sensor Integration Group, Advanced Manufacturing Research Institute, Shimo-Shidami, Moriyama-ku, Nagoya 463-8560, Japan. Tel.: +81 52 736 7240; fax: +81 52 736 7244.
E-mail address: w.shin@aist.go.jp (W. Shin).

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doi:10.1016/j.apsusc.2008.01.162

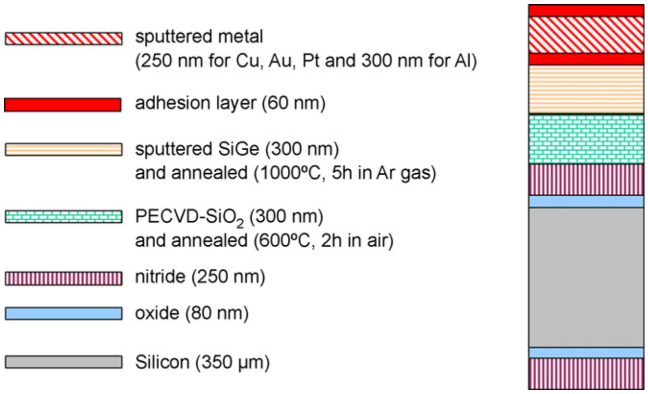

Fig. 1. Cross section of the metal stack structures for the electrical contacts on SiGe thin film.

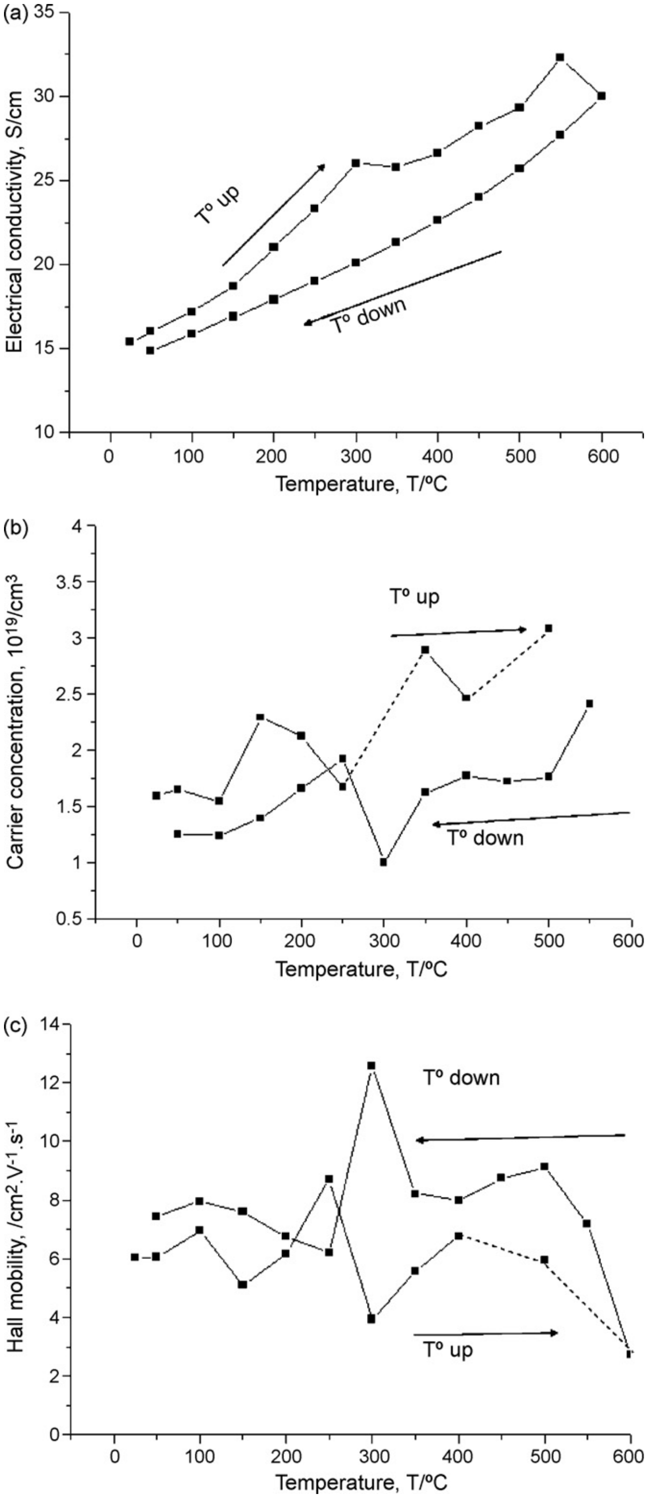

Fig. 2. Electrical conductivity (a), carrier concentration (b) and Hall mobility (c) of the SiGe measured by a four-probe method and using the Ta/Pt/Ta electrical contact.

Au, Pt or Al) for the electrical contacts. The thicknesses of the Ti, Ta, Cu, Au and Pt layers were measured by a profilometer (Tencor Profiler KLA) after deposit. Thicknesses of 60 nm and 250 nm were measured for Ti, Ta adhesion layers and Cu, Au, Pt layers, respectively. A thickness of 300 nm was measured for the Al layer using cross sectional pictures taken by FE-SEM. The stack structures were then annealed for aging at 500 °C during 24 h.

The SiGe layer was characterized by X-ray diffraction (XRD, Rigaku, RINT2100), Seebeck coefficient and Hall effect measurements. The Seebeck coefficient was measured in a furnace from the voltage and temperature difference between the two sides of the SiGe thin film. A Seebeck coefficient of 0.11 mV K^{-1} was evaluated at 100 °C [9]. The Hall measurements were conducted using a four-probe technique system (Toyo Tech., ResiTest8340HT) at various temperatures and with a magnetic field of 0.75 T (see Fig. 2). The temperature was increased (T° up) from room temperature to 600 °C and decreased (T° down) down to room temperature. Fig. 2a shows the electrical conductivity of the 300 nm-SiGe layer. After heating up to 600 °C, the SiGe electrical conductivity decreases slightly due to the partial desorption of the dopant which reduces the carrier concentration in the SiGe during heating as shown in Fig. 2b. Due to the dopant concentration decrease, the carriers are more mobile in the SiGe layer as shown by the slight increase of the Hall mobility during cooling (T° down in Fig. 2c). In Fig. 2b and c, few data were removed due to the high noise level in the measurement of the carrier concentration and the Hall mobility (dotted lines).

A surface morphological study was carried out with an optical microscope and AFM to observe the surface changes in the metal layers after aging. The aging condition was annealing the samples in air for 24 h at 500 °C (ramp up 2 h and natural cooling after annealing). An AFM (Seiko Instruments, SPI3800N/SPA400) was used in air and dynamic force mode (scan speed: 1Hz) with a silicon cantilever (vertical elastic constante: 3 N/m, resonance frequency: 24.9 kHz, quality factor in air: 169.7) and 10-µm-height tip covered by rhodium. Three electrode multilayers of Ti/Au/Ti, Ti/Pt/Ti and Ta/Pt/Ta layers have been characterized as they are used in the fabrication of the electrical contacts of catalytic micro-thermoelectric hydrogen sensors (µ-THS) [9,10]. The transmission line method (TLM) was used for this characterization of the electrode contacts, which was originally proposed by Shockley et al. [11] and later reviewed by Berger [12], for the measurement of the specific contact resistivity of planar Ohmic contacts. Fig. 3 shows a schematic representation of a two-