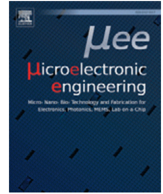
Microelectronic Engineering 176 (2017) 71–74

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee



Research paper

Direct bonding of ALD Al_2O_3 to silicon nitride thin films

S. Laganá *, E.K. Mikkelsen, R. Marie, O. Hansen, K. Mølhave

DTU Nanotech, Dept. of Micro and Nanotechnology, Technical University of Denmark, Ørsteds Plads Building 345C, DK-2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 13 October 2016
Received in revised form 19 December 2016
Accepted 31 January 2017
Available online 5 February 2017

Keywords:
Direct bonding
ALD
Silicon nitride
TEM

ABSTRACT

Direct bonding is an advanced joining technique for bonding of silicon based surfaces at low temperature without any specific surface pretreatment. The main purpose of this work is to develop new techniques to enhance the fabrication process for nanofluidic systems for in situ transmission electron microscopy (TEM) by improving low temperature annealing bonding strength when using atomic layer deposition of aluminum oxide. We have investigated and characterized bonding of Al_2O_3–Si_xN_y (low stress silicon rich nitride) and Al_2O_3–Si_3N_4 (stoichiometric nitride) thin films annealed from room temperature up to 600 °C without pretreatment prior to the pre-bonding. We find that bonding of Al_2O_3–Si_xN_y and Al_2O_3–Si_3N_4 is favorable in a temperature range from room temperature to 600 °C. We report bonding strength of 1300 ± 150 mJ/m^2 comparable to and in some case even higher than that of other materials Al_2O_3 can be bonded to. Preliminary tests demonstrating a well-defined nanochannel system with ~100 nm high channels successfully bonded and tests against leaks using optical fluorescence technique and transmission electron microscopy (TEM) characterization of liquid samples are also reported. Moreover, the current bonding method can be also used for further MEMS applications.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Direct bonding, also known as fusion bonding, was demonstrated in 1986 as an efficient method to bond silicon wafers [1,2]. The advantages of this technique have proven to be crucial for MEMS, microelectronics, micro/nanoreactors and optoelectronics device fabrication. Over the last decade integrating buried insulating material like SiO_2 in SOI substrate has been widely used and studied. However, due to the reduction in the length scale of many devices, SiO_2 substrates have shown some limitations such as leakage current or self-heating [3]. Thus replacement of SiO_2 by some other high-k dielectric material such as Al_2O_3 and Si_3N_4 is gaining importance [4,5]. The investigation of Si_3N_4 as an SOI replacements has been studied since 1992 while since 2010 [6] Al_2O_3 found some applications. Harendt et al. were the first to successfully bond silicon nitride (Si_3N_4) to silicon (Si) [7]. However, due to the difference in expansion coefficients between Si_3N_4 and Si upon annealing cracks appear in the nitride layer. Fusion bonding of 1 µm thick low-stress Low Pressure Chemical Vapor Deposited (LPCVD) Si_xN_y–Si_xN_y was achieved by Sanchez et al. by polishing the surface to reduce the roughness from 2.9 nm down to 0.3 nm [8]. The bonded strength was found to be between 1.1 and 2.9 J/m^2 after 2 h at 1000 °C. More recently, Reck et al. have bonded Si_3N_4–Si_3N_4 without any pretreatment and obtained bonding strength at 2 J/m^2 after several hours at 1150 °C. They also showed that exposure to buffered HF (bHF) during the pre-bonding cleaning, could lead to failure of the bonding due to absence of a thin oxynitride layer [9]. In addition, Gui et al. have shown that the surface roughness is a critical factor to achieve a strong bond [8]. On the other hand little is presently known about atomic layer deposited (ALD) Al_2O_3 substrate surfaces in terms of bonding performance. Suni et al. proposed for the first time bonding of ALD Al_2O_3 with Si, SiO_2 and Al_2O_3 in a temperature range >400 °C [10]. They reported lower bonding strength at 900 °C due to a possible phase transition of Al_2O_3 leading to unexpected formation of voids. Beche et al. characterized the bonding of ALD Al_2O_3 to itself in detail highlighting de-bonding phenomena and formation of a high density of voids both at 400 °C and 800 °C [11]. ALD is a slower process than CVD, but here this is not an issue, since we need only 2, 3 or at most 10 nm thick Al_2O_3 layers, which in a multi-wafer ALD system can be deposited almost as fast as similar CVD films, when the overhead for loading of the wafers is taken into account.

Recently, direct bonding to form nanofluidic channel devices has found several applications in electron microscopy (EM) for imaging of liquid samples thanks to the leak-proof capability offered by the bonding technique [12,13]. In this work we have investigated and characterized for the first time bonding of Al_2O_3–Si_xN_y and Al_2O_3–Si_3N_4 thin films annealed from room temperature up to 600 °C without pretreatment prior to the pre-bonding. Direct bonding experiments were performed on both patterned and un-patterned wafers with a total bonded dielectric layer thickness of up to ~110 nm. Low aspect ratio nanochannels ($h \ll w$) were successfully fabricated using this novel technique. The main purpose of our experiments is to develop new techniques to improve the fabrication process for nanofluidic systems for TEM technologies. ALD Al_2O_3 improves bonding whenever the use of SiO_2 is not possible, for instance due to built-in compressive stress or if high anneal

* Corresponding author.
E-mail address: simla@nanotech.dtu.dk (S. Laganá).

http://dx.doi.org/10.1016/j.mee.2017.01.038
0167-9317/© 2017 Elsevier B.V. All rights reserved.

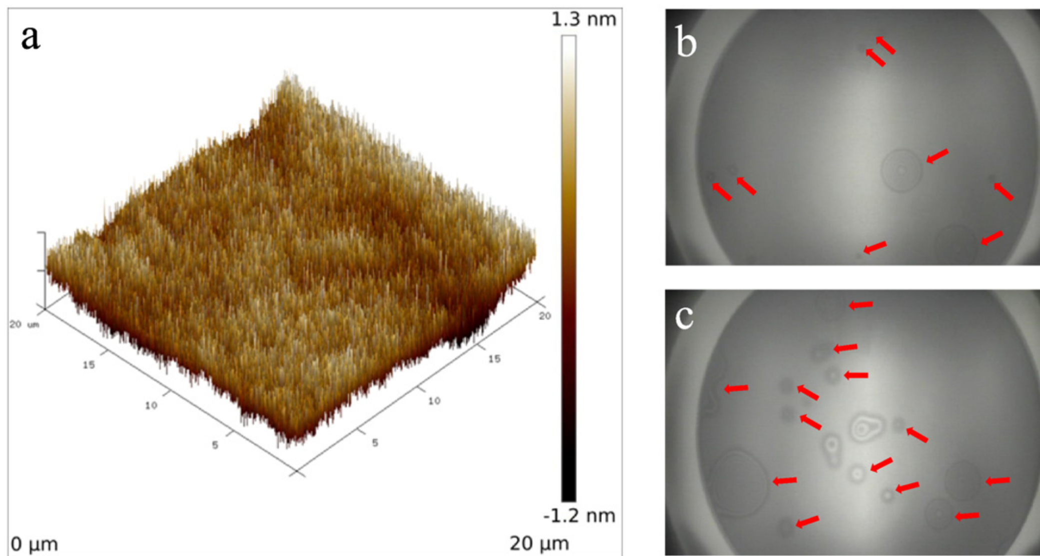


Fig. 1. a) AFM image of 20 µm × 20 µm surface area of 10 nm amorphous ALD Al_2O_3 deposited on ~50 nm of Si_3N_4. The RMS roughness was measured to $R_a = 0.35$ nm; b) and c) Infrared transmission image of b) Si_3N_4–Al_2O_3/Si_3N_4 and c) Si_xN_y–Al_2O_3/Si_xN_y. Voids are indicated by red arrows. The height of the voids is indicated by the number of the Newtonian fringes.

temperatures should be avoided. The ALD Al_2O_3 additionally offers novel surface chemistry for in situ liquid TEM experiments since it is also present in the channel and is a relevant surface for many applications such as studies of catalytic processes.

2. Fabrication

Different layer architectures were fabricated in order to reveal the bonding capability of the ALD Al_2O_3–Si_xN_y and ALD Al_2O_3–Si_3N_4 architecture. Approximately 50 nm thick Si_xN_y (low stress silicon rich) and Si_3N_4 (stoichiometric nitride) were grown by LPCVD using trichlorosilane and ammonia at 830 °C on standard boron doped double polished 100 mm, 350 ± 15 um thick (100) silicon wafers. Amorphous ALD Al_2O_3 films of 10 nm were deposited at 250 °C using tri-methyl-aluminum (TMA) and water as active precursors. The surface quality of Al_2O_3 and Si_xN_y/Si_3N_4 were characterized as deposited using atomic force microscopy (AFM). Pre-bonding of ALD Al_2O_3–Si_xN_y and ALD Al_2O_3–Si_3N_4 was carried out right after alumina deposition. Sometimes a water ultrasonic bath was applied for silicon rich nitride in order to remove particles caused by the deposition process. The pre-bonding was carried out by aligning the wafers by their main flat and dropping one on top of the other and followed by application a force (~10 N) on the center of the top wafer to initiate the bonding front. In order to investigate the effects of the temperature on the bonding strength, wafers were annealed in a range of temperature from RT to 600 °C for both Si_xN_y and Si_3N_4 samples for 8 h in N_2 atmosphere. Infrared microscopy (IR) was performed to evaluate bonding quality and bonding characterization.

3. Results and discussion

For spontaneous bonding, the root mean square (RMS) surface roughness has to be below 0.5 nm [14]. The surface roughnesses of Si_xN_y and Si_3N_4 were measured right after deposition by atomic force microscopy (AFM) in tapping mode in air. The RMS roughness of 1 um × 1 um areas were found 0.41 nm and 0.35 nm, respectively. The values are in good agreement with those measured by Reck et al. [9] Fig. 1 shows a 20 µm × 20 µm square scan of 10 nm amorphous ALD Al_2O_3 on top of ~50 nm of Si_xN_y. The ALD RMS roughness was measured to be 0.35 nm. Thus, the roughness of both Si_xN_y/Si_3N_4 and amorphous Al_2O_3 is sufficiently low for spontaneous bonding, and therefore chemical mechanical polishing (CMP) is not needed. Bonding inspection was carried out using an IR camera. Fig. 1b) and c) shows IR images of bonded Si_3N_4-Al_2O_3/Si_3N_4 and Si_xN_y-Al_2O_3/Si_xN_y wafers annealed at 600 °C,

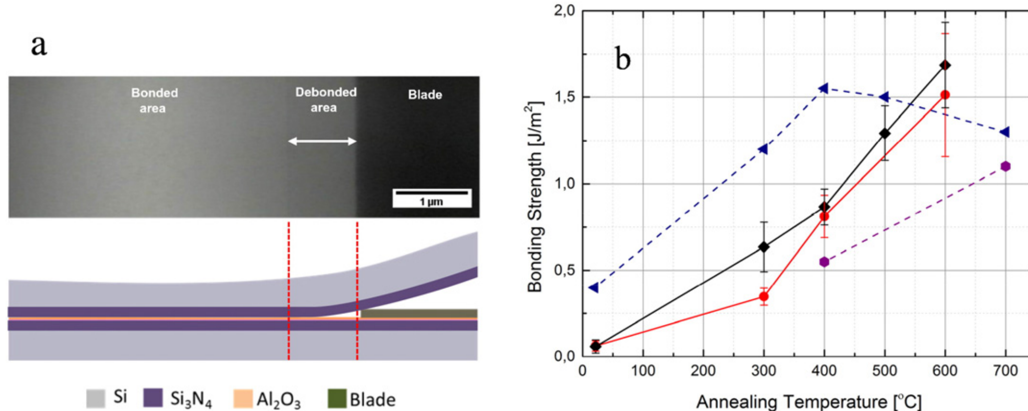


Fig. 2. a) Experimental bonding strength measurement using the crack propagation method. A thin blade of 100 µm was inserted between the bonded wafers. Then the length of the deboned area was measured; b) Trend in bonding strength for Si_xN_y/Al_2O_3–Si_xN_y (black) and Si_3N_4/Al_2O_3–Si_3N_4 (red). Dotted lines results from Si/Al_2O_3 [10] (dotted blue) and SiO_2/Al_2O_3 [11] (dotted purple).

Download English Version:

https://daneshyari.com/en/article/4970927

Download Persian Version:

https://daneshyari.com/article/4970927

Daneshyari.com