Atomic Level InP/Si Wafer-Scale Bonding in Low Temperature

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Abstract

We demonstrate atomic level InP/Si wafer-scale bonding after 300^{0}C annealing. The annealing voids at the bonding interface caused usually by plasma exposure are avoided. The pre-patterns to escape the byproducts of bonding reaction are not necessary if the optimal situation of InP/Si wafer bonding is performed.

INTRODUCTION

Wafer fusion bonding technology has been used to fabricate SOI (Silicon-on-insulator) material. However, a lot of applications require in combination with disparate materials to implement the advanced multifunctions. For example, researchers are being interested in the investigation of III-V and Si in order to gain III-V unique property in conjunction with the matured Si CMOS technology platform for SOC and so-called optoelectronic integrated circuits (OEICs) [1,2]. The III-V is also one of the options as a NMOS channel for the future CMOS or more Moore's [3]. The heteroepitaxy is usually considered as the one of main approaches for heterogeneous integration but the defects generated by lattice mismatch between III-V and Si materials seriously influence on, even completely destroy epitaxial layer crystal quality [4]. Also, the heterogeneous integration employed by adhesives cannot experienced post-processes over 300^{0}C [5]. It is not requested to match lattice constant for heterogeneous material integration by wafer fusion bonding technology but the direct wafer bonding has to be carried out under the low temperature to avoid the crack owing to the thermal expansion coefficient difference. On the other hand, the well-known smart-cut technology [6] (i.e. thin layer transfer) demands strong bonding in low temperature for the exfoliation. The composited wafer consisted of different materials can withstand higher temperature after the layer transfer achievement thanks to the flexibility of the thin single crystal layer. As a result, a strong bonding in low temperature is the fundamental to heterogeneous integration.

In special, 8.1% lattice-mismatch between InP and Si resulted in 10^7cm^{-2} dislocation density in heteroepitaxy [7]. Therefore, direct wafer bonding is an important choice to achieve high quality InP/Si material system. The report [8] obtained InP/Si wafer-scale bonding by O_2-plasma activation by 300^{0}C annealing but a great number of vertical outgassing channels (VOCs) patterned prior to wafer bonding have been employed. Moreover, the high defect density at the bonding interface was still in existence due to the lack of optimal InP/Si wafer fusion bonding process and shown by scanning electron microscopy (SEM) in ref. [8]. But, it is worth noting that the wafer fusion bonding by plasma activation closely depends on the annealing procedure [9]. In other words, the number of annealing voids associated with bonding quality may be increased over time if an improper activation is induced. Consequently, the process of wafer bonding will directly affect on the long term reliability. Atomic level InP/Si wafer bonding by 150^{0}C annealing was viewed by Tong but B_2H_6 plasma treatment in their experiments resulted in boron contamination [10].

In this paper, we present a method of the low temperature InP/Si wafer bonding by means of O_2-plasma activation to achieve atomic level wafer bonding in the case of a 300^{0}C annealing for 120 hours without any pre-patterns on bonding surface for outgas.

EXPERIMENTALS

All of Si and InP wafers with 2" and (100)-orientation were used in our experiments. The silicon wafers were first cleaned by the solution of H_2SO_4:H_2O_2 (6:1) in 120^{0}C and then experienced RCA1 (70^{0}C) and RCA2 (70^{0}C) cleaning, followed by spin-dry after de-ion water rinsing. InP wafers were first cleaned using solution of HF:H_2O (1:50) and HNO_3 (70wt.%) for 10s and 30s, respectively. Finally, the InP wafers were blown by nitrogen for drying after a de-ion wafer rinsing prior to wafer bonding. InP and silicon wafers were pretreatment by O_2-plasma for different exposure duration. The other parameters in the O_2-plasma process were a 100sccm oxygen flow, 0.4bar chamber pressure and 100W RF power supply. The prebonding was manually conducted in clean ambient.

All of the InP/Si bonded pairs were annealed at 300^{0}C for 120 hours. The infrared imaging system was employed for the comparable inspection variation of interface voids before and after annealing. The interface microstructure of InP/Si direct wafer bonding was characterized by transmission electron microscopy (TEM).

RESULTS AND DISCUSSIONS

Fig. 1 shows infrared images of InP/Si bonded pairs for different O_2-plasma exposure time before and after annealing at 300^{0}C for 120 hours, respectively. Fig. 1b compared to Fig.

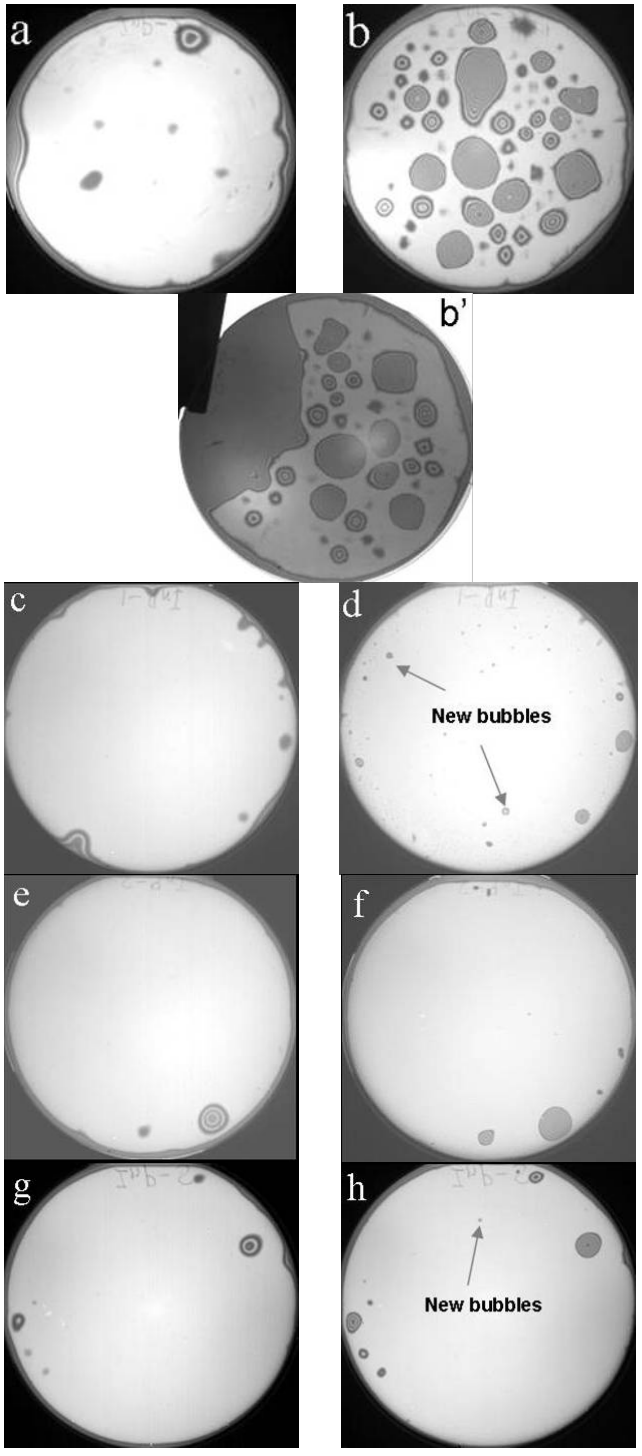

Figure 1. Infrared images of InP/Si bonded pairs, a, c, e, g, before annealing for 0s, 20s. 40s, 60s plasma exposure, respectively. b, d, f, h corresponding to a, c, e, g after annealing at 300^{0}C for 120hrs. b' with a blade from b.

1a, the more voids (i.e. non-bonded areas) are shown in Fig. 1b after annealing. The long length of the observed propagating crack was indicated in Fig. 1b' to illustrate the very weak bonding as the InP/Si interface was inserted by a blade for testing bonding strength [11]. However, the bonding strength is too strong to test based on the opening-crack method [11] due to InP broken after an annealing at 300^{0}C for 120 hours if the O_2-plasma exposure time is applied.

As can be seen, the voids were quickly decreased or almost removed as O_2-plasma exposure was performed. It was obvious that the contaminants from hydrocarbon on the InP wafer resulted in thermal voids in Fig. 1b but the O_2-plasma exposure plays an important role in the bonding surface cleaning in order to suppress thermal voids [9]. Moreover, Fig. 1f compared to Fig.1d, the thermal voids were precisely further decreased and nearly completely removed. On the other hand, the annealing voids originated from the byproducts of bonding reaction seem to occur (shown in Fig.1h). TEM sample from the cross section of the sample f was successfully fabricated and observed in Fig. 2.

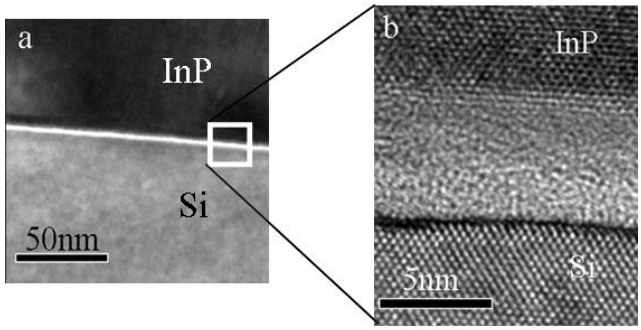

Figure 2. Cross section TEM images of InP/Si bonding interface after annealing at 300^{0}C for 120hrs, a and b stand for TEM and HRTEM pictures, respectively.

An amorphous layer with about 8nm at the bonding interface is clearly shown in Fig. 2b. The amorphous layer is usually existed in hydrophilic wafer bonding [12]. In our experiments, EDS (energy dispersive X-ray spectroscopy) has verified that oxygen element was included in the amorphous but In, P, and Si elements. Therefore, O_2-plasma assisted wafer bonding can be compatible and accepted for microelectronic industry. Furthermore, it is worth noting that the O_2-plasma exposure not only improves bonding strength but also deeply clean surfaces to remove hydrocarbon. The hydrocarbon may be generated by the appliances in wet cleaning process in original InP wafer production procedure. However, the hydrocarbon may not be noted in the epitaxy or other processes thanks to its volatility over 600^{0}C but it gives rise to serious voids for low temperature wafer bonding. This situation is similar to Si/Si low temperature wafer bonding [9].

CONCLUSIONS

Atomic level InP/Si direct wafer bonding was successfully achieved after 300^{0}C annealing and the voids at bonding interface were not caused without pre-patterns to

exhaust the byproducts of bonding reaction. O_2-plasma exposure not only largely improve the bonding strength but also clean further bonding surface to remove the contaminant from hydrocarbon such as the Si/Si low temperature wafer bonding.

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