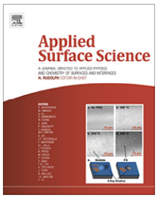
Applied Surface Science 445 (2018) 16–23

Contents lists available at ScienceDirect

Applied Surface Science

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



Full Length Article

Modified pulse laser deposition of Ag nanostructure as intermediate for low temperature Cu-Cu bonding

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ARTICLE INFO

Article history:
Received 21 November 2017
Revised 6 March 2018
Accepted 9 March 2018
Available online 15 March 2018

Keywords:
Cu-Cu bonding
A Velcro Ag nanostructure
Pulse laser deposition
Mechanical interlock

ABSTRACT

To lower the Cu-Cu bonding temperature and save the time of the bonding process applied for 3D integration, the Ag nanostructure deposited by pulsed laser deposition (PLD) was designed and decorated on the Cu pads as intermediate. Influences of different PLD process parameters on the designed Ag nanostructure morphology were investigated in this work. The large nanoparticles (NP) defects, NPs coverage rate on the Cu pad, and NPs size distribution were adopted to evaluate the PLD parameters based on the NPs morphology observation and the Cu-Cu bonding quality. The medium laser power of 0.8 W, smaller distance between target and substrate, and protective container should be applied in the optimized PLD to obtain the Ag nanostructure. Then a loose 3D mesh Ag nanostructure consisted of the protrusions and grooves was formed and the morphology observation proved the nanostructure deposition mechanism was contributed to the block of nano-film nucleation and nanoparticles absorption. Finally, the relationship between the bonding temperature and pressure suitable for the Ag nanostructure had been determined based on shear strength and interface observation. The results revealed the combination of higher bonding temperature (250 °C) and lower pressure (20 MPa), or lower bonding temperature (180 °C) and higher pressure (50 MPa) can both achieve the bonding process with the short bonding time of 5 min and annealing at 200 °C for 25 min in vacuum furnace.

1. Introduction

3D heterogeneous integration has been one of the potential solutions to improve the performance and increase integration density of integrated circuit (IC), which requires robust and time-saving chip-to-chip interconnection with high electrical and thermal conduction [1,2]. Cu-Cu thermal-compression bonding could satisfy the demand of the interconnection, but it needed high bonding temperature above 300 °C and long bonding time over 30 min to achieve atom diffusion at the bonding interfaces [3–6]. Nanostructure has already been applied in the thermal bonding because of its nano-effect and high specific surface area [7–13]. The bonding mechanism of these attempts still referred to atom diffusion during high temperature, so the high temperature and long bonding time were also required. In our previous work, a nanostructure intermediate was proposed and developed on Cu pads for Cu-Cu bonding and pulse laser deposition (PLD) was used to deposit the nanostructure [12,13]. The time-saving low temperature Cu-Cu bonding was completed with the help of Ag nanostructure, which confirmed the bonding a promising inter-chip interconnection technology. However, the nanostructure deposition strategy by PLD has not been reported yet. Currently, PLD process was often used to prepare nano-film [14,15] or nanoparticles (NPs) in different liquid [16,17], which were applied in other applications such as organic reaction intermediates, biotechnology and nanoplasmonic devices. There were few studies reported for nanostructure fabricated by PLD applied for microelectronic interconnection. Lower bonding temperature and shorter bonding time required in the 3D integration also presented more challenge to the PLD process for depositing the optimized nanostructures and bonding process as well. Consequently, more contribution should be made to study the effect of the PLD process on the nanostructure morphology and optimize the corresponding bonding process.

In this work, we designed a Velcro Ag nanostructure to achieve the time-saving low temperature bonding. Different PLD process parameters were optimized to obtain Ag nanostructure. Large NP defects (droplet) were the general defects in PLD process [18,19] so it was used to evaluate the optimization of the PLD process parameters. NPs size distribution representing the nano-effect of NPs was adopted to access PLD process because it would highly

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https://doi.org/10.1016/j.apsusc.2018.03.076
0169-4332/

influence bonding temperature. Based on the law of Mass Conservation, there must be sufficient NPs so that the mechanical lock can be realized and continuous bonding interface without voids can be formed. Therefore, coverage rate was also put forward to assess the NPs morphology. Confirmatory bonding experiment was also used to identify the effect of coverage rate on bonding quality so that the optimized PLD strategy could be finally determined. Then a loose 3D mesh Ag nanostructure consisted of the protrusions and grooves was formed and the morphology observation proved the nanostructure deposition mechanism was contributed to the block of nano-film nucleation and nanoparticles absorption. To achieve the bonding without voids by using the Ag nanostructure, relationship between different bonding parameters such as bonding temperature and pressure were setup based on the evaluation of bonding strength and interface microstructure. Bonding by using Ag nanostructure with no voids at the interface was achieved at the low temperature of 180 °C with the pressure of 50 MPa for 5 min and annealing temperature of 200 °C for 25 min.

2. Experimental

Fig. 1(a) shows the designed Ag nanostructure resembling the Velcro consisted of 3D mesh with protrusions and grooves, and nanoparticles (NP) surrounding the mesh. 3D mesh with protrusions and grooves provides the opportunity to form the mechanical interlock when the two bonded interfaces with nanostructures were bonded. While NPs surrounding the mesh can melt themselves to fill in the gap between the interfaces, which can not be accomplished due to merely mechanical interlock bonding mechanism. In the Ag nanostructure fabrication process, femtosecond pulsed laser with the pulse duration of 50 fs and the wave length of 800 nm was used, which will largely decrease the NP size. Silicon chips with the dimension of 5 mm ∗ 5mm and 10 mm ∗ 10 m m were separately prepared before PLD deposition. Fig. 1 sketched the process flow including bonding structure fabrication, nanostructure deposition, patterned nanostructure process and bonding process. Traditional industry processes were used to form the underlying Cu pad with the adhesive layer TiW, routing layer Al and insulation layer SiO_2. To deposit Ag nanostructure on the Cu pad, non-Cu area was coated with thick photoresist by photolithography as shown in Fig. 1(c). Then Ag nanostructures over the non-Cu area were taken away by removing the photoresist as shown in Fig. 1(d). Coverage rate, particle size distribution and large defects were used to characterize the effect of process parameters on the NPs morphologies. Finally, the optimized PLD parameters to deposit Ag nanostructure for low temperature bonding

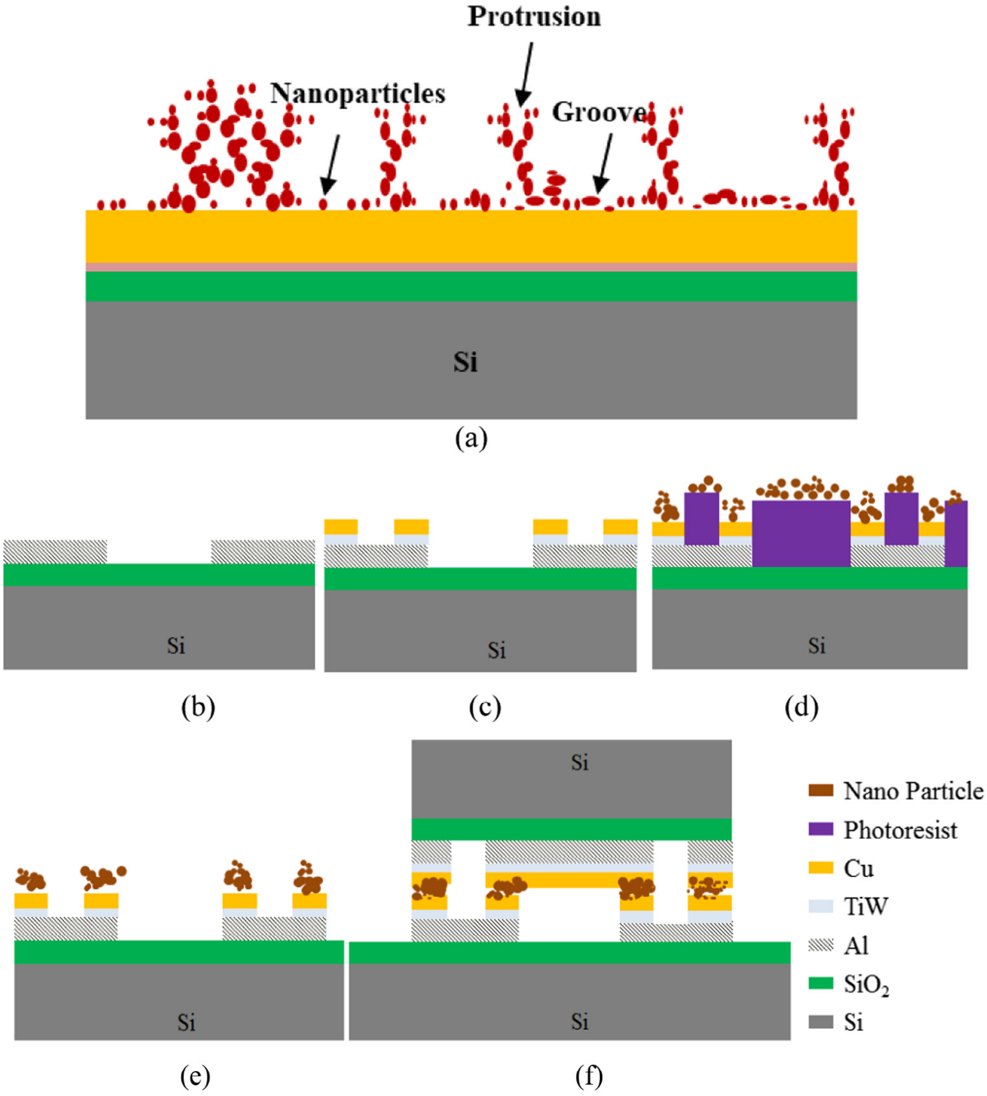

Fig. 1. (a) Designed nanostructure Morphology; Process flow, (b) Al routing layer, (c) patterned Cu pad with adhesive layer TiW, (d) Photoresist (PR) protection and nanostructure deposition, (e) PR removed and nanostructure patterned and (f) bonding process.