OPTIMIZATION OF LOW TEMPERATURE NH₃ PLASMA ACTIVATED DIRECT BONDING

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ABSTRACT

Previous work has described the existence of low temperature NH₃ plasma activated direct bonding but has not provided the details that allow this technique to be applied to a variety of microstructure applications. This paper describes the standard surface preparation and optimization of the NH₃ plasma activation for low temperature silicon bonding. Procedures discussed include cleaning, wafer handling, plasma activation, bonding, and annealing. Critical parameters investigated in the NH₃ plasma treatment are flow rate, power, and time. The optimal setting is 75 sccm, 50 W, and 5 minutes.

INTRODUCTION

Low temperature NH₃ plasma bonding has been described in earlier publications [1, 2, 3]. Applications of these techniques have been have also been described [4]. Mechanical considerations have also been described in detail [5]. While these publications have described the basic concepts and applications of this technology the details of practicing and optimizing this technique have not been presented. This paper gives a detailed description of the practice and optimization of this technique.

EXPERIMENTAL PROCEDURES

Criteria for successful direct silicon to silicon bonding include consideration of the flatness, waviness, and roughness of the material. For this optimization experiment, wafers with a radius of curvature greater than 100 m, roughness less than 1 nm, and a waviness parameter greater than 10⁻⁶ were used. By meeting these material characteristics, the stress induced by bonding will not exceed $\sigma_i = 10^6$ which ensures a conformal pair [5].

The cleaning procedure consists of a standard RCA clean comprised of the following: base bath [NH₄OH-H₂O₂-H₂O (1:1:7)] and acid bath [HCL-H₂O₂-H₂O (1:1:6)] without a subsequent BOE dip. Samples were handled with only vacuum tweezers to prevent possible damage to the surface. The silicon samples were prepared for bonding by activating the surfaces in an NH₃ plasma using a Technics PECVD Series 900. The bonded pairs were annealed for 20 hours at 300° C.

The parameters investigated in this optimization process were the flow rate, power, and time for the NH₃ activation as seen below:

Flow Rate (sccm)	Power (W)	Time (min)
35	50	5
55	125	10
75	200	15

A 3 x 3 x 3 experimental matrix was created. Six sample sets were prepared for each matrix element. The bonds were rated after the anneal cycle using a classification system of 0 to 5, with 5 being a bond without any voids. See table 1 for description of classification system.

Rating	Description
0	No Bond
1	Multiple fringe patterns
2	soft bond, or small region (spot) of solid bond, bond strength ~ 200 ergs/cm ²
3	Solid bond to 1/3 of contact area, soft elsewhere, bond strength ~ 500 ergs/cm ²
4	Solid bond to 2/3 of contact area, fringe patterns at edges, bond strength ~ 750 ergs/cm ²
5	99.9% bonded area, void free, bond strength ~ 1000 ergs/cm ²

Table 1: Bond Classification

An example of a type 5 bonded pair is shown in the TEM in Figure 1. This figure illustrates the two silicon chips with an oxide formed on each surface during the cleaning procedure. The total thickness of the oxide is 90 angstroms. Localized micro-voids can be seen along the bonded interface. This TEM is comparable to the quality achieved under high temperature bonding.

Figure 1: TEM of a type 5 silicon bonded pair. Magnification 370K

RESULTS & ANALYSIS

The optimal condition was found to be 75 sccm, 50 W, and 5 min. with an average rating of 4.2 and a bond strength of about 750 ergs/cm². In Table 2, the averages and binomial distribution are shown for the other elements of the matrix. This setting was analyzed statistically using a binomial distribution. Taking into consideration the bonding and quality probabilities, the statistical analysis proposes that there is a 33.5 % probability of finding consistent high quality bond characteristics in this group as compared to the other groups. These statistics are indigenous to each trial, meaning they are relative and not absolute. It shows how the results of each trial compare to the others and not to the overall experimental run.

35 sccm	50 W	125 W	200 W
5 min	-	-	2.33, .01%
10 min	-	-	2.00, .01%
15 min	-	-	1.67, .01%
55 sccm			
5 min	2.08, .05%	-	-
10 min	2.42, .01%	-	3.42, 2.9%
15 min	1.50, 0%	-	-
75 sccm			
5 min	4.12, 33.5%	-	3.83, 1.6%
10 min	4.00, 1.6%	-	-
15 min	2.83, .05%	-	-

Table 2: Average rating and binomial distributions for experimental conditions. These were computed only for averages greater than 1.

CONCLUSION

Optimization of low temperature NH₃ plasma activated direct silicon bonding was investigated and determined to be 75 sccm, 50 W, and 5 min. The optimized parameters found produced a substantially higher probability of finding consistent high quality bonds than the other conditions investigated.

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