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ON THE DIRECT BONDING OF TWO SILICON SURFACES: EXPERIMENTS AND MODELING

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Summary. *Silicon direct bonding is a well known process in optic. In this communication we will present principles of molecular adhesion, chemical and mechanical characterization of the interface and a numerical study to predict the mechanical resistance of assemblies.*

Silicon direct bonding consists in joining two surfaces without any adhesive or additional material at room temperature. This bonding is due to short range intermolecular and interatomic attraction forces such as Van Der Waals or hydrogen bonds [1]. Many covalent bonds – which appear with thermal treatments – are a guaranty of better mechanical performance. Bonding process is divided in several stages: physical preparation of surface (control of roughness and flatness), surface activation by solvents, adhesion of the both surfaces and thermal treatment in order to rigidify the interface.

This bonding is of particular interest to spatial instrument fabrication (interferometers, slicers…) because of the high precision of the process and dimensional stability of the assemblies. However, this bonding process is poorly reproducible. That is why the space-rating of the technology needs a process control, reproducibility of their implementation and an improvement in the mechanical performance of adhesive bonds in vibratory environment.

The three main parameters for direct bonding are the material deformability, the surface energy of adhesion – which depends of the surface chemistry – and the roughness of both surfaces to adhere [2]. Indeed, it is clear that the bonding will be easier with small Young modulus, high surface energy of adhesion and the most important a short roughness. Otherwise this would result in a weak contacted zones and bonding defaults up to prevent sticking.

In this study, some experimental and numerical results will be presented.

In a first part, chemical analyses such as surface wettability and X-ray photoelectron spectroscopy where presented. Results show only few differences between silicon surface and

silicon debonded surface. This allows us to say that the direct bonding at room temperature is reversible.
Shear tests and double cantilever beam tests – with and without thermal treatments – were made in order to characterize the mechanical performance of the interface and study the best annealing for the bonding process.
In a second part, we will compare different way of modeling this adhesive contact. More precisely, we will compare models – in the framework of the finite element method – of surface debonding under the effect of an external force.
The first one is the virtual crack closure technique criterion based on the linear elastic fracture mechanics. The strain energy released when a crack is extended by a certain amount is the same as the energy required to close the crack by the same amount [3].
The second one is the RCCM model based on the introduction of a variable which characterizes the damage state of adhesive bonds [4]. In this model, the evolution of the adhesion variable depends on the Dupré's energy and the stiffness of the adhesive.
The third one uses cohesive elements where each node represents a surface area of 0.5mm² (the cell size during roughness measurement). This is a strength model. Indeed, two bonded nodes – belonging respectively to each surface – will debond when the external force is up to a predefined force on those nodes. This force at each node is calculated adding the forces acting on each asperity in the precedent surface area. Those forces will be determined thanks to different physical models taking into accounts surface energy of adhesion and roughness. For this last model, we will also compare sinusoidal and Gaussian distributions [5-8].
The aim of this numerical study is the prediction of the mechanical resistance of assemblies.

REFERENCES

[1] Q.Y. Tong, U. Gosele, Semiconductor wafer bonding: recent developments, *Mater. Chem. Phys.* 37:101-107, 1994
[2] C. Gui, M. Elwenspoek, The effect of surface roughness on direct wafer bonding, *J. Appl. Phy.* Vol: 85, 10, 1999
[3] V. Ranatunga, Finite element modeling of delamination crack propagation in laminated composites, *Proceedings of the World Congress on Engineering 2011 Vol III WCE 2011*
[4] M. Raous, L Cangemi, M. Cocou, a consistent model coupling adhesion, friction and unilateral contact, *Comput. Methods Appl. Mech. Engrg* 177:383-399, 1999
[5] K.L. Johnson, The adhesion of two elastic bodies with slightly wavy surfaces, *Int. J. Solids Structures* 32:423-430, 1995
[6] G, Liao, T. Shi, Effect of surface characteristic on room temperature silicon direct bonding, *Sensors and Actuators A* 158:335-341, 2010
[7] K.L. Johnson, K. Kendall, A.D Roberts, Surface energy and the contact of elastic solids, *Proc. R. Lond. A.* 324:301-313, 1971
[8] G.L. Liao, X.H. Lin, L. Nie, Surface roughness modeling for silicon direct bonding, *IEEE Transaction on components packaging and manufacturing technology*, Vol 1, Issue 8, 1171-1177, 2011