Chapter 4

BONDING

Bonding is a set of technological procedures which permanently seal solid-state materials with smooth and flat surfaces, most often by chemical reactions. This method of material sealing is commonly used in microsystem technology for bonding of unprocessed flat wafers, deeply micromachined wafers, with movable micromechanical structures, whole wafers or particular chips or small details. Bonding is not only a simple packaging method of microsystem technology, as most often classified, it is the integral procedure of microsystems fabrication, playing a role in front-end as well as back-end technological procedures. The widest application in microsystem technology has been in the bonding of two silicon wafers and bonding of silicon wafer to glass substrate, as well as the bonding of chips and components made of these materials.

Bonding significantly broadens the technological capability of formation of 3-D microsystems coming from deep micromachining of silicon because:

- it allows the fabrication of multi-layer, sandwiched, micromechanical structures, in which each layer can contain three-dimensional structures,
- it allows the multi-chip production of microsystems with many micromechanical structures and/or microelectronic structures bonded to the single silicon or glass substrate platform,
- it is a very good technique for packaging of microsystems.

Bonding, regardless of its type, consists mainly of the three following steps:

- preparation of surface for bonding (cleaning, activation),
- alignment and pre-bonding of details,
- final formation of bonding.

These steps are closely related to, and depended on, the type of bonding procedure applied. Bonding is carried out in the range of high (>700°C), medium (200–500°C) or low temperatures (20–200°C). It can be either a thermally activated process, without electric field excitation (fusion bonding, bonding through the low-melting glasses, eutectic bonding, HF and NaOH bonding,
foil bonding) or supported by electric field excitation (anodic bonding). Bonding can be carried out in a clean air, in an inert/chemically active atmosphere or in vacuum.

Micromechanical sandwiched silicon structures are mainly fabricated by means of high-temperature bonding. Silicon-glass structures are produced by use of a wider range of medium-temperature bonding techniques. Among these are anodic bonding, so-called glass frit bonding using low-melting glasses, and eutectic bonding. Low-temperature bonding techniques, such as foil bonding, resist bonding and glueing of details, are employed more rarely. Mixed techniques of bonding are also very often applied.

All the above-mentioned techniques of bonding (sometimes called the micromechanical sealing of materials) will be discussed in this chapter, which is divided into two parts. In the first part, non-electric bonding techniques suitable for microsystem technology are presented. This material – based on the analysis of literature data and the author’s experience – begins with the presentation of the methods of preparation of surfaces for bonding. Next, the mechanism of silicon to silicon fusion bonding for hydrophilic and hydrophobic surfaces is presented, as well as the influence of the SiO$_2$ interlayer on the process of fusion bonding and the quality of bonding (the transitory layers). Then, fusion bonding through other dielectric layers (Si$_3$N$_4$, SiC, diamond-like, etc.) is discussed, along with the main micromechanical applications of high-temperature fusion bonding. Finally, low-temperature fusion bonding, bonding through sodium silicates, and boron and phosphorus glasses, HF bonding, eutectic bonding and foil bonding are described.

In the second part of this chapter anodic bonding is discussed. To start with, the historical background and a general description of the method are presented, and then the characterization of the properties of glasses, leading to the description of anodic bonding. Next, the mechanism of anodic bonding is analyzed, including the phenomena occurring by the cathode and by the anode (at silicon and glass interface), formation of the depletion layer, the role of electrostatic pressure and the discussion of Baumann’s and Schmidt’s models of the process. Next, the transport of charges is discussed and the activation energy of anodic bonding is determined. The conditions of a good anodic bonding of silicon to different types of glasses are researched, as well as the quality, force and minimal conditions of bonding. Flexures, induced stresses, hardness after the process and the optimization of these parameters are analyzed. Multi-layer, sandwich bonding is discussed, along with the special techniques of silicon-glass and silicon to glass bonding through all the useful dielectric and metallic layers. In addition many examples of applications of anodic bonding, in the construction and fabrication of various silicon-glass microsystems, are presented.

### 4.1. SURFACE CLEANING AND ACTIVATION

The process of bonding of materials requires an adequately prepared surface of bonded wafers. A surface needs to be clean and dustless, because wafers must