Available online at www.sciencedirect.com

ScienceDirect

Sensors and Actuators A 133 (2007) 457–466

SENSORS AND ACTUATORS A PHYSICAL

www.elsevier.com/locate/sna

Die separation and packaging of a surface micromachined piezoresistive pressure sensor

Ingelin Clausen *, Ola Sveen

Department of Physics, University of Oslo, P.O. Box 1048, NO-0316 Oslo, Norway

Received 11 November 2005; received in revised form 20 April 2006; accepted 9 May 2006
Available online 3 July 2006

Abstract

The processing steps required to obtain a useful single medical sensor assembly are discussed, starting from an entire silicon wafer with thousands of surface micromachined sensors. Experiences concerning dicing and packaging of a piezoresistive pressure sensor are described, together with proposals for solutions. Problems with fracture of essential sensor structures are solved by use of a wafer protection tape. Existing solutions for flip–chip bonding and design of substrate for electrical interconnection are pushed to their limits due to the very small size of the novel sensor. As many of the processes can be simplified by an improved MEMS design, critical points related to the design are addressed.

Keywords: MEMS design; Piezoresistive pressure sensor; Medical application; Packaging; Dicing; Flip–chip bonding

1. Introduction

Design of sensors for medical applications involves both medical and technical experts. The medical community considers "proof of concept" in animals to be more important than results from laboratory tests. Communication of results and progress of work to the medical experts may therefore be more comprehensible when applying test schemes as normally used in medicine. The objective of the work described in this paper was at first to show proof of concept by implanting a miniature pressure sensor into a pig's brain. The involved work, however, is also vital to find technological solutions for general MEMS applications.

The discussed pressure sensor is part of a sensor system being developed for measurement of human brain pressure in patients with hydrocephalus [1]. Hydrocephalus is a condition with abnormal accumulation of brain fluid. The build-up of brain fluid can cause an increased brain pressure, which left untreated may result in brain damage or even death. Treatment of hydrocephalus often involves implantation of a fluid shunt system (Fig. 1). This system may help to stabilize the brain pressure by draining accumulated brain fluid away from the brain to other areas of the body where it can be reabsorbed. A standard ventricular rubber catheter used for hydrocephalus operations has typically an inner diameter of 1.5 mm (Fig. 2). Our sensor has been designed so that the pressure sensor can be placed inside the tip of this catheter.

A microelectromechanical system (MEMS) obviously has a benefit when size is important. The micromachining technology, and especially surface micromachining technology[1] is convenient for small and planar structures. A powerful approach for measuring pressure is to determine the deformation of a diaphragm under applied pressure. Several physical effects can be used for sensing the diaphragm deformation, but for a piezoresistive sensor, separation of electronics and sensor element is possible and therefore makes an extreme miniaturization achievable. The basis for the measurement system being developed is a piezoresistive, surface micromachined pressure sensor.

Other implantable pressure sensors exist, but most of these utilize a capacitive measuring principle where the necessary electronics need to be placed in the proximity of the sensor [2,3]. These sensors are therefore too big for our application. A

* Corresponding author. Tel.: +47 22 06 73 81; fax: +47 22 06 73 21.
E-mail address: ingelin.clausen@sintef.no (I. Clausen).

[1] Surface micromachining technology make use of the wafer substrate and depose thin films on top, in contrast to bulk micromachining technology which modifies the structure of the whole wafer by changing the properties in some areas and etching away others.

0924-4247/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2006.05.011

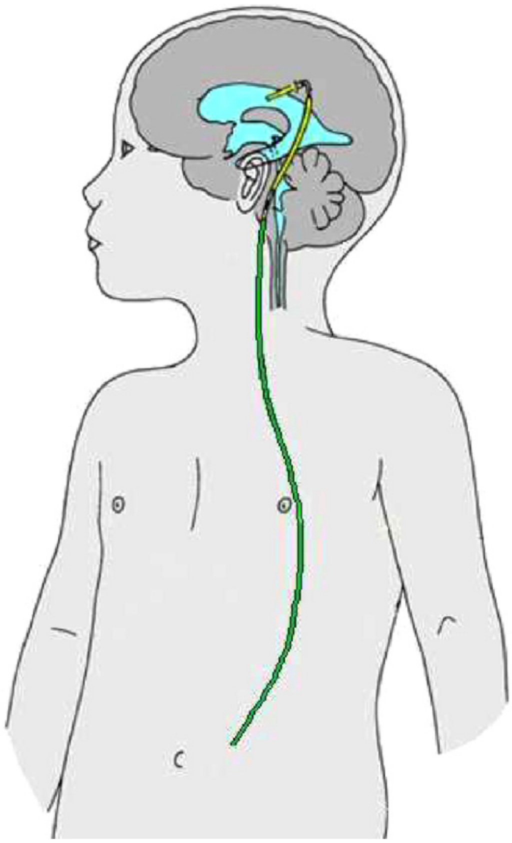

Fig. 1. Drainage system for treatment of hydrocephalus, helping to stabilize the brain pressure by draining away accumulated brain fluid to other areas of the body where it can be reabsorbed.

smaller fiber optic pressure sensor is commercially available, but the repeatability does not meet the accuracy demands set by the neurosurgeons, and the measurement principle implies connections penetrating the skin with subsequent risk of infections [4]. To our knowledge no suitable sensor with the necessary small dimensions exists today. The sensor presented in this paper has lateral dimensions of 700 μm × 700 μm. Details about the sensor design are given in Section 3.

A number of highly specialized technological pre-processes as dicing, bonding and interconnection to signal conditioning unit are needed before testing in animals can be a reality. These steps are also required to convert a MEMS from wafer level into a final MEMS application. The combination of these processes may be very complex and lots of details have to be considered to obtain a successful result. Due to the very small size of the novel sensor, existing technologies are pushed to their limits. Experiences concerning the different processes are described in Section 4 together with our solutions and the physics behind. As some of the experienced difficulties can be a reduced by a modified sensor design, recommendations regarding the sensor design are discussed in Section 5.

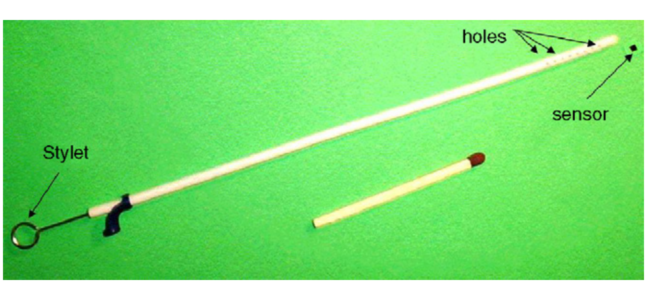

Fig. 2. Codman Holter® ventricular silicone rubber catheter for hydrocephalus surgery, with an inner diameter of 1.5 mm. A 5 cm long match is shown for comparison. A steel stylet is placed in the catheter to make it stiff enough to be pushed through the brain tissue. The brain fluid enters the catheter through holes in the side-wall and a tiny pressure sensor can therefore be placed in the tip of the catheter without disturbing the drainage.

2. The sensor system

The sensor system consists of a piezoresistive pressure sensor placed inside the brain ventricles, an electronic module including a signal conditioning unit placed outside the scull, but underneath the skin, and an external, wireless readout unit which supplies energy to – and transfers data from – the implanted pressure sensor (Fig. 3). A closer description of the total sensor system is given in [1].

We envision a system where the sensor is embedded in the drainage catheter, so that it is inserted together with the catheter during brain surgery. In this way the sensor could be introduced without causing any extra brain damage. If we place the sensor inside the catheter tip, the sensor has to be enclosed by an intermediate layer with low compressibility as silicone oil or gel to ensure efficient pressure transmission from the brain fluid to the sensor. The wires connecting the sensor to the electronic module situated under the skin can be embedded in the catheter wall.

3. Sensor design

The sensor presented in this paper is designed by others and is proprietary [5]. Basic principles for the design are still given below.

The very limited space within the brain sets the requirements for the design of the pressure sensor. Surface micromachining technology is suitable since very thin structures can be produced. A piezoresistive sensor is chosen instead of a capacitive one because it is less sensitive to capacitance in the connecting electrical wires for low excitation frequencies, and separation of electronics and sensor element is therefore possible. Piezoresistive, surface micromachined pressure sensors have the ability to overcome the needs for extreme miniaturization. The lateral dimensions of the novel sensor discussed in this paper are 700 μm × 700 μm. The thickness of the sensor is given by the silicon wafer thickness of 670 μm, but as the active structure is located in the uppermost 5 μm layer (Fig. 4), the sensor thickness can be considerably reduced by wafer thinning.

The piezoresistive measuring principle is based on inducing a mechanical stress in the sensor structure. The sensing element is a circular polycrystalline silicon diaphragm with polysilicon piezoresistors on top of a sealed vacuum cavity (Fig. 5). An absolute sensor, i.e. with vacuum in the cavity, has been made.

The circular shape of the diaphragm prevents the stress concentration that appears in square ones. We can look upon the pressure sensor diaphragm as a circular plate with clamped edges