A HIGH-STABLE PRESSURE SENSOR BASED ON A SOI HETEROSTRUCTURE AND MEMS TECHNOLOGY FOR AN INTELLIGENT INSTRUMENTS

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Abstract:
The time stability of pressure transducers is a necessary condition which provides the measurement and computation of a flight data by an aircraft computer with required accuracy [1].

As compared with Weston Aerospace up-to-date high-stable electromechanical pressure transducers [2], which use a resonance effect in a vibrating cylinder, semiconductor microelectromechanical sensors (SMEMS) have advantages in possible integration with a signal microprocessor circuit and in group manufacturing based on advanced MEMS technologies [3].

Honeywell is known to be conducting efforts in replacing electromechanical sensors with microelectromechanical ones in an aircraft flight data system [4].

Electrical p-n junctions in conventional silicon sensors [3] are prerequisites for the time instability of sensors and an aircraft flight data measurement system as a whole. Conventional micromechanical piezoresistive sensors, which contain electric p-n junctions, have a limited operational temperature range due to the exponential dependence of reverse current from the p-n junction temperature as known in the semiconductor physics

$I_o \sim n_i^2 \sim \exp[-\Delta E_F /(kT)]$.

The capabilities of measurement error correction using microprocessor techniques for transfer characteristic linearization, temperature compensation and other parameters become significantly complicated due to the instability of the transfer characteristic of conventional SMEMS.

The developed concept [5], which eliminates the usage of p-n junctions in SMEMS, forms the basis for the proposed solutions and the principles of developing integral high-stable SOI-based membrane-type pressure sensors with a monolithic tensoframe.

Keywords: MEMS sensor, SOI, monolithic tensoframe.

1. INTRODUCTION

High accuracy measurement of a flight data is a critical task for flight safety. This task can be only solved, if the high time stability of physical and mechanical parameter sensors is provided.

Recent years clearly show a trend of implementing MEMS devices based on silicon and silicon-on-isolator (SOI) heterostructures, such as microaccelerometers, microgyroscopes, microelectronic pressure sensors, into aerometric systems of aircraft, as well as automatic engine control systems. In addition, high requirements are established for measurement accuracy with the exposure to destabilizing factors, such as shock and vibration loads, aggressive environment and others, within a wide temperature range. Nevertheless, residual stresses in semiconductor wafers after mechanical operations, including the thinning process for an instrument plate in a SOI heterostructure (a disrupted layer) produced with the Direct Bonding method [6], or the cutting process in a SOI heterostructure generated with the Smart Cut method [7], provide one of the causes of measurement errors in transducers based on piezoresistive sensors.

For piezoresistive sensors based on a symmetric Whitestone bridge, the presence of residual stresses in micromechanical structures causes a “zero” signal and results in the need in specific circuit solutions to minimize this signal (“zero” calibration), which are not always effective due to additional random errors resulted from material aging during 12-15 years of the aircraft service life (for unserviceable avionics).

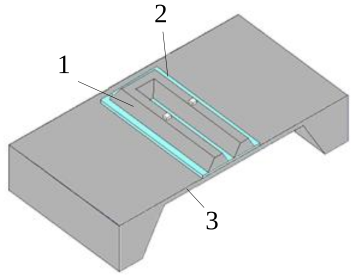
The other cause of stress occurrences may be a difference in the coefficients of thermal expansion of silicon and dielectric material, which forms a thin connection layer in a SOI heterostructure, e.g. if silicon dioxide is used as a connection layer.

The hysteresis error in well-known ADZ Nagano sensors based on a silicon-on-isolator (SOI) structure and a metal membrane [8] can reach 1%, that essentially decreases measurement accuracy.

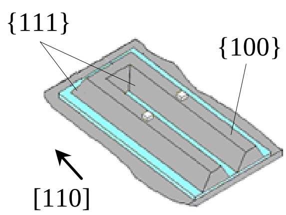
Pressure transducers based on microelectromechanical sensors with a SOI structure and an integral monolithic tensoframe (MEMS-SOIMT) [9] have an advantage as compared with transducers with conventional silicon sensors, as they have high time stability and a wide operating temperature range. In addition, the microelectromechanical sensors with a SOI structure feature no diffusion of dopes into a silicon membrane, that otherwise causes local mechanical stresses on the membrane and consequent stress relaxation.

2. DESIGN OF THE SOIMT MICROELECTROMECHANICAL SENSOR

The microelectromechanical sensor (MEMS-SOIMT) is a sensitive component (chip) which measures 5.0 mm x 5.0 mm x 0.56 mm. It is produced using MEMS and microsystem technologies (Fig. 1). The main features of the sensor include a monolithic integral tensoframe, an ideal isolation between the Wheatstone bridge circuit and a lowresistance silicon membrane due to a thin glass layer (Fig. 1), and no p-n junctions in a sensitive component structure [7].



a)



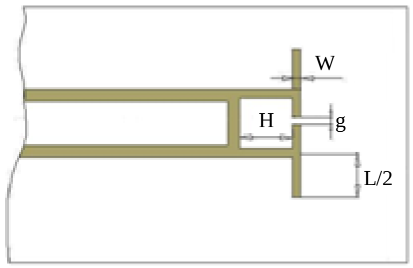
b)

Fig. 1: Cross-Section of a Microelectromechanical Piezoresistive Sensor Based on SOI structure: (*a*) 1 – integral monolithic tensoframe, 2 – thin dielectric layer, 3 – membrane; (b) crystallographic orientation of a tensoframe after anisotropic chemical etching of silicon (100)

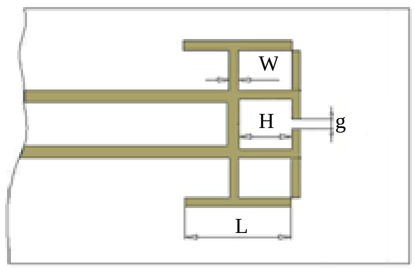
3. INVESTIGATION OF A FRAME UNDERCUT BIAS SYMMETRY

3.1 Mask topologies

Mask topologies have been developed to investigate the rate adjustment process during ACE of silicon (100). The topologies feature either an angular compensator configuration (Fig. 2), or the size of compensator elements (Table 1).



a)



b)

Fig. 2: Fragments with Angle Compensators for ACE Process: with Configuration 1 (a) and Configuration 2 (b)

Table 1: Linear Dimensions of Compensator Elements

Confi-guration	Version	Length L, μm	L/2, μm	Height H, μm	Width W, μm
1	1-1	-	140	150	40
1	1-2	-	130	50	100
2	2-1	240	120	10	40

The investigations have been conducted using samples with the two-layer structure of the masking coating, which consists of thin films of silicon dioxide and phyrolithic silicon nitride.

Etching has been performed in the 33% КОН water solution at 82±2 ^{0}C with continuous solution mixing in a reactor.

The linear dimensions of the frame have been measured with a Karl-Zeiss optical microscope using the experimental samples to assess the frame undercut bias symmetry. The quality of silicon microprocessing has been inspected a Kodak digital camera and Qunta-2000 REM Microscope.

3.2. A frame undercut bias symmetry

Well-known microelectronics technologies are used in MEMS-SOIMT sample etching, except the photolithography process on a relief surface. The feature of relief surface lithography is that a mask with holes for contact pads is superimposed on a microprofiled plate shaped as multiple 202 μm high frames on its surface.

While in microprofiling of an integral monolithic frame with the ACE technique the in adequate compensation of the convex angle undercutting process can become the cause of asymmetry and, therefore, unbalance for a Wheatstone measuring bridge.

As shown on figures 3 and 4, it is obvious that the frame undercut bias depends on the height and width ratio of the angular compensators, while the other dimensions of the mask are equal (Fig. 2a).

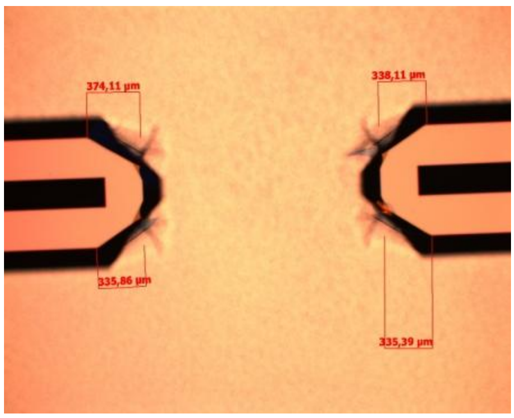


Fig. 3: Photo of tensoframe sample fragments with the frame undercut bias equal 38,25 μm

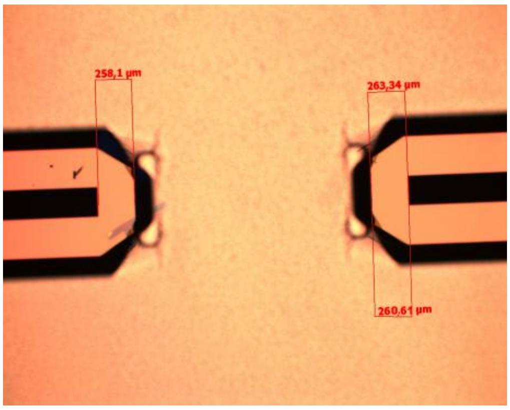
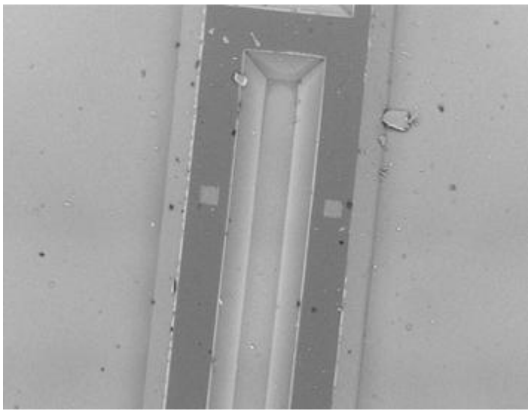


Fig. 4: Photo of tensoframe sample fragments with the frame undercut bias equal 2,73 µm

If the samples are etched to a depth of 202 µm, the large frame undercut bias 374.11 µm – 355.86 µm = 38.25 µm is obtained for H/W = 0.5 (Fig. 3) as compared with an undercut bias of 263.34 µm – 260.61 µm = 2.73 µm for H/W = 3.75 (Fig. 4). Simultaneously, a slight asymmetry caused by nonuniform frame angle undercut etching is observed on both frame sides in the first case.

4. RESULTS AND DISCUSSION

As a result of the ACE from the mask (Fig. 2a), a 3D frame with a regular geometric shape as a symmetric Wheatstone test bridge (Fig. 5, Fig. 6) is manufactured.



x 50

Fig. 5: REM Image of a MEMS-SOIMT Sample Fragment with a frame of a regular shape

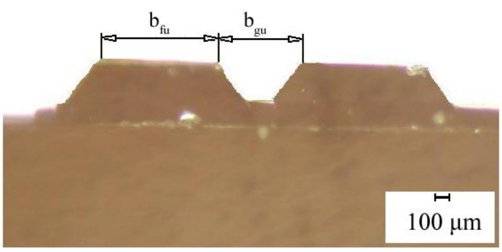


Fig. 6: MEMS-SOIMT Sample Fragment Split Digital Photo

c)

Fig. 7: Digital Photo of a Tensoframe with Measured Design Parameters

Fig. 5 shows a MEMS-SOIMT sample with a frame of a regular shape which is produced by using mask configuration 1 for H/W = 3.75 (Table 1, version 1-1).

Fig. 7 shows a 3D frame with the measured basic frame design parameters.

The comparison of the frame design parameters for three samples of MEMS-SOIMT sensors (Fig. 7) has shown that the design parameters are slightly different from the calculated ones (Table 2). Nevertheless, when the zero shift is measured, the unbalance of the Wheatstone bridge is within tens to hundreds of millivolts (for 5 VDC power supply), that supposes mechanical stresses on the sensor membrane.

Table 2: Deviations in Integral Frame Dimensions after Microprofiling

Design Parameter	Dimensions, µm		Δ, µm
	Design	Measured	
Frame Length, L_f	3573.0	3538.12	−34.88
Frame Width, b_{fu}	200.0	150.67	−49.33
Gap, b_{gu}	327.0	371.65	+44.65

Expected technical specifications of SOIMT-based pressure transducer are shown at the Table 3.

Table 3: Expected technical specifications of SOIMT Based Pressure Transducer

Pressure measuring Range, kPa	10 … 150
Operating Temperature Range, K	213 to 523
Basic Error with a Confidence Probability of 0.95	0.1 of measurement limit, max
Long-Term Instability, % per year	0.1, max
MTBF, hour	10^4, min
Life Time, hour	30000
Overload Pressure	1.5…2,0 of measurement range

CONCLUSIONS

1. The important challenge of improving the long-term stability of transfer performance for piezoresistive sensors is to minimize residual stresses and the stress relaxation process, when destabilizing factors, such as shock and vibration loads, aggressive environment and other factors typical for severe operational conditions of aerospace equipment, affect within a wide temperature range.

This task is especially pressing for piezoresistive sensors based on SOI heterostructures, taking into account the technology features of SOI wafers manufactured with the Direct Bonding or Smart Cut methods.

2.The investigations of etch rate adjustment, convex angle protection, as well as contact lithography on the relief surface of a silicon wafer enable a new technology to be developed for MEMS-SOIMT piezoresistive sensors with a symmetric Wheatstone bridge based on an integral monolithic silicon tensoframe.

3. Designing a structure and a technology for piezoresistive measuring transducers of mechanical parameters should take into consideration the required minimization of residual mechanical stresses and stress relaxation processes to improve transducer measurement accuracy.

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