AN IMPROVED MONOLITHIC ACCELEROMETER

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An improved 100g DC accelerometer is being developed. Prior monolithic accelerometers [1], [2] were not optimized for wide operating temperature range or maximum sensitivity for a given f_n. Present capacitive or piezoelectric designs [3], [4] are unable to measure static acceleration. An existing 100g Insouth design was used as a starting point for a new development effort. Design goals included: 1 mV/g sensitivity with 10 volt excitation, f_n > 2KHz, low span error, low cross axis sensitivity, and < 2% bias over a temperature range of -65°C to +95°C. The design would be capable of reasonable yields to produce a low cost unit.

The design approach utilized performance data from an existing Insouth accelerometer as a starting point for a factor change analysis. Cantilever equations relating f_n and ε to beam length, width, thickness and proof mass were decomposed into proportionalities as shown in Figure 1.

These proportionalities allow accurate design modification as well as flexibility to quickly trade-off parameter changes. The design goals required an increase in sensitivity and higher f_n than the previous accelerometer. It is obvious from Figure 1 that a simultaneous increase in f_n and ε (sensitivity) is impossible with any one parameter change. However, a two parameter change will allow both f_n and sensitivity to be improved. Reducing beam length should be used to raise f_n because the improvement of f_n occurs at a higher rate than the resulting degradation of sensitivity. Similarly, increased proof mass, and decreased width and thickness should be used only to increase sensitivity because ε (sensitivity) will increase at a higher rate than f_n degradation.

The final mechanical design shown in Figure 2 is a 54 x 63 mil die having a cantilever beam 500 µm wide and 575µm long. The silicon proof mass is 500 µm x 500 µm at the top surface and 200 µm thick. In order to minimize beam length (measured to the center of mass) and maximize proof mass a material much denser than silicon is required for the proof mass. Gold preforms 20 x 20 x 3 mils were used on the improved accelerometer. The 3 mil thickness moves the center of mass of the composite proof mass up to the flexure plane and eliminates the moment that causes cross axis pickup. In addition to the improvement of cross axis rejection the added preform increases sensitivity by an order of magnitude.

The strain sensors are ion implanted or diffused piezoresistors. Sensor arrangements included a full active full bridge (FAFB) and a depletion MOSFET structure similar to a full active half bridge (FAHB). The 500 Ω FAFB is a conventional strain gauge bridge chosen for its simplicity and low impedance output. The same resistor layout rotated 90° is used for longitudinal and transverse elements of the bridge to prevent layout induced offset.

The 6 µm gate metal on the depletion MOSFET sensor is located on the beam flexure line where maximum ε occurs. The gates are intended to deplete the piezoresistor and increase its resistance in a region of maximum strain resulting in an electrically controllable $\Delta R/R$ enhancement. Since both MOSFET elements are gate controllable as shown in Figure 3, the output offset is also electrically adjustable.

The improved accelerometers were tested over temperature as well as mechanically characterized. The f_n of the units without gold proof mass is 7.8-8.5 KHz in good agreement with the calculated 7.46 KHz. Experimental test results for the FAFB with 10 volt excitation are given in Figure 4, and frequency response plots of accelerometers with and without gold preform mass are shown in Figure 5.

The MOSFET sensor was too heavily doped to saturate at low voltages. However, a $\Delta R/R$ enhancement was observed with positive gate bias. The effect of gate voltage on sensitivity is shown in Figure 6 for a 10 volt excitation and gate voltages from zero to 40V. The MOSFET sensor output vs. temperature can be varied with gate control and could be used as a temperature compensation method. Figure 7 shows the output change with temperature for gate voltages from zero to 10 volts and no acceleration applied.

Parameter	Relationship to Natural Frequency	Relationship to Maximum Strain
MASS	$f_n \propto \frac{1}{m^{1/2}}$	$\epsilon_{max} \propto m$
LENGTH	$f_n \propto \frac{1}{L^{3/2}}$	$\epsilon_{max} \propto L$
WIDTH	$f_n \propto W^{1/2}$	$\epsilon_{max} \propto \frac{1}{W}$
THICKNESS	$f_n \propto t^{3/2}$	$\epsilon_{max} \propto \frac{1}{t^2}$

Fig. 1. Table of Cantilever Proportionalities

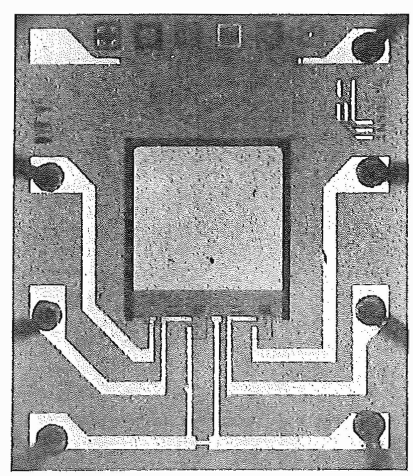


Fig. 2. Photograph of FAFB Monolithic Accelerometer

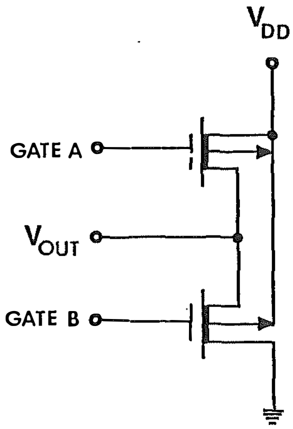
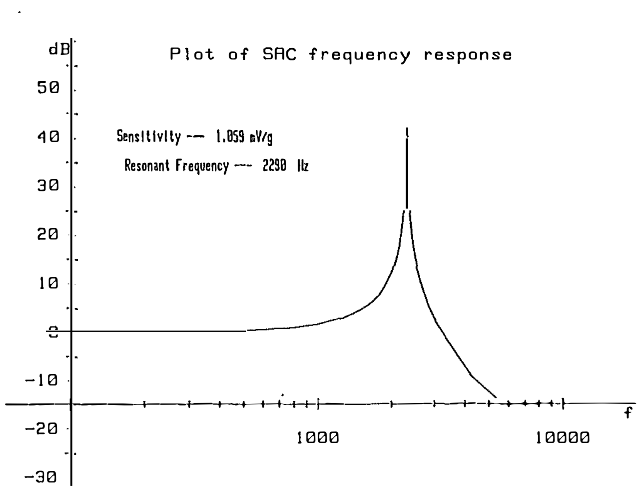


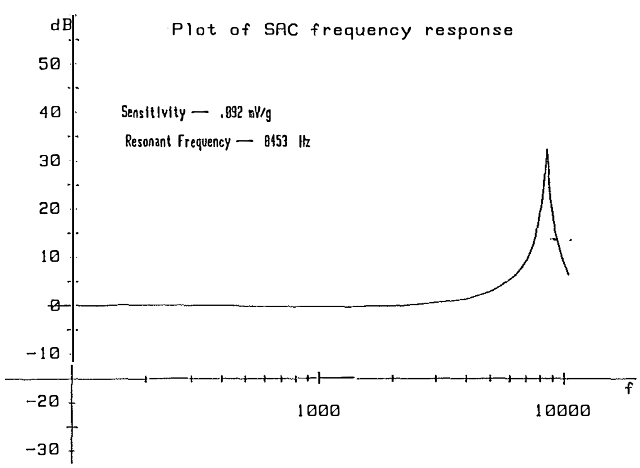
Fig. 3. Schematic of FAHB MOSFET Accelerometer

Scale Factor	.8 - 1.4 mV/g
f_n	2.4 KHz
Cross Axis Pickup	1% - 6%
Bias Over Temperature -65° + 95°C	3%
TCGF	<1100 ppm/°C
Non-Linearity	<5%

Fig. 4. FAFB Accelerometer Test Data



(a)



(b)

Fig. 5 Frequency Response of FAFB Monolithic Accelerometer.
(a) With Gold Proof Mass. (b) Without Gold Proof Mass.

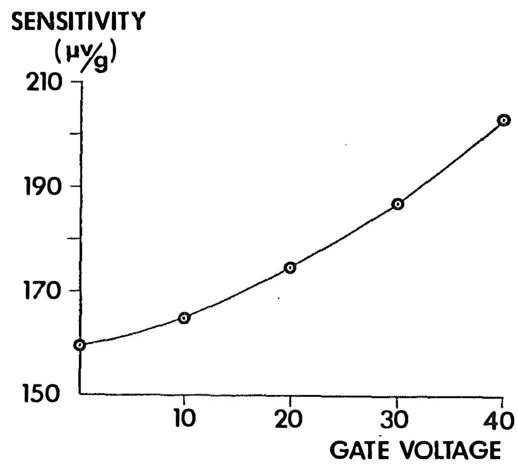


Fig. 6. MOSFET FAHB Accelerometer Sensitivity vs. Gate Voltage. Bridge Excitation was 10 Volts.

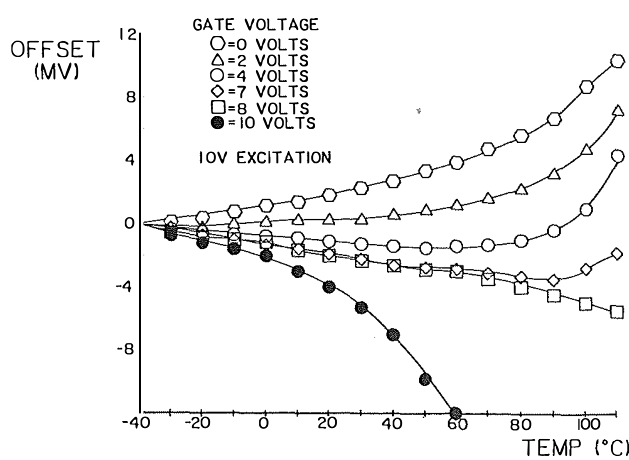


Fig. 7. MOSFET FAHB Output Offset Change vs. Temperature for Several Gate Voltages. All Data Taken with 10V Excitation and Referenced to -40°C Data Point.

References:

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