Subproject C5: "Development and characterisation of a high aspect ratio vertical FET sensor for motion detection"

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1 INTRODUCTION

Nowadays, inertial sensors for car dynamics stabilisation, acceleration detection and human body motion monitoring are popular MEMS applications. Additionally, motion/position detection is often required for actuators too (xy stages, switches, etc.). At present, these systems are usually based on piezoelectric or capacitive sensors. While especially the latter principle is already used for mass production of inertial sensors an increase of the signal/area consumption ratio is desired. That's why alternative approaches have been presented looking for a direct integration of mechanical and electrical principles [1, 2, 3, 4].

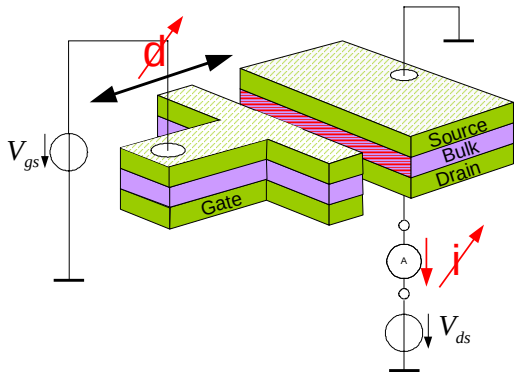

Figure 1. *Schematic view of the vertical FET*

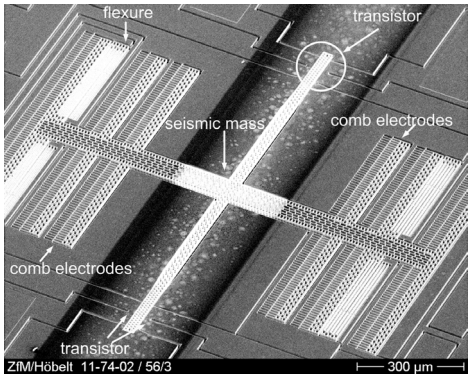

Figure 2. *SEM view of the vertical FET*

2 FET SENSOR

The detection principle of the FET sensor for motion sensing is the electrical field effect. A schematic of the structure is shown in figure 1. The system consists of a laterally moving spring-mass-system (figure 2). There are two arms at the seismic mass. Transistor regions are located at the end of the arms. The moving mass (single crystalline silicon) is acting as a gate electrode (in plane). The air gap between the channel and the gate electrode decreases / increases due to the deflection of the mass caused for example by the moment of inertia. A displacement of the mass changes the air gap of the vertical FET influencing the capacitance of the gate insulator.

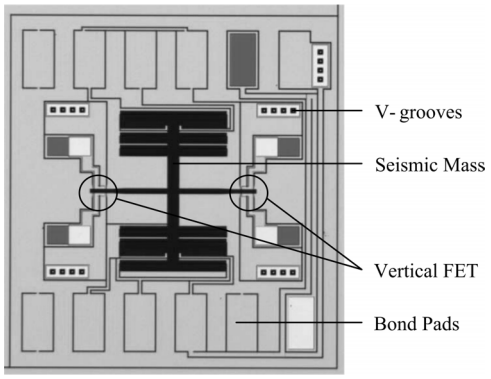

Figure 3. *Layout of the transistor*

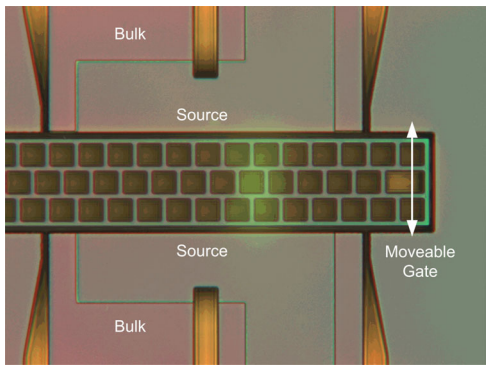

Figure 4. *Light-optical microscope view of the transistor*

$$C_{insulator} = \left(C_{air}^{-1} + C_{ox}^{-1}\right)^{-1}. \tag{1}$$

$$\frac{C_{ox}}{C_{air}} \approx 60 \;\Rightarrow C_{insulator} \approx C_{air}$$

In addition to the vertical FET signal the movement is also detected capacitively by comb electrodes at both sides of the seismic mass for comparison. Further comb electrodes are used to control the working range and to force the mass deflection. Thus a variable electrostatic interaction decreases/increases the gap between the channel and the mass (gate).

To find out the relationship between the geometric dimension (table 1) and the sensitivity of the structure, the performance of the sensing element is simulated using a process and device simulator. An analytical model is used to evaluate the dimensionally optimised arrangement between the transistor and the spring-mass-system in order to design a vertical FET with maximum sensitivity. The simulation data are compared with measurement results from fabricated sensors.

The basic expression for the MOS drain current in saturation is:

$$I_{dSat} = \frac{1}{2}\mu \cdot C_{insulator}(d)\frac{W}{L}\left[V_g - V_{th}(d)\right]^2 \tag{2}$$

where μ is the carrier mobility, W is the MOS channel width, L the MOS channel length, V_g the applied gate voltage and d the distance between the channel and the gate. The expression for threshold voltage of a vertical FET is:

$$V_{th} = \phi_{ms} + 2\phi_f - \frac{Q_{ss}d}{\varepsilon_0} + \frac{d}{\varepsilon_0}\sqrt{4\varepsilon_0\varepsilon_{rSi}eN_A\phi_f}\,. \tag{3}$$

In this equation Φ_{ms} represents the contact potential between bulk and gate, Φ_f the electrostatic potential of the substrate, Q_{ss} additional positive charge at the silicon-oxide interface due to imperfections during growth of the gate oxide, ε_0 the permittivity of the air, ε_{rSi} the permittivity of the silicon and N_A the number of acceptor atoms at the oxide-semiconductor surface. To improve the signal-to-noise ratio, to suppress the dc offset and to enlarge the output signal, the vertical FET can be used in a differential sensor arrangement based on two vertical FET's. Thereby a differential amplifier stage is necessary.

Table 1. *Geometrical data of the vertical FET*

Channel length	10 µm
Channel width	90 µm
Aspect ratio	10 µm to 2 µm
Air gap minimum	1 µm
Air gap maximum	8 µm

3 PROCESS

A high aspect ratio technology represents the base technology for the fabrication of the sensor structures. Using a five mask process, laterally movable structures with n-type and p-type doped layers are fabricated. Starting with ion implantation processes and Si-epitaxy a well-defined dopant distribution is required. The fabrication of the devices presented in this paper is mainly based on the application of more or less conventional MEMS process steps. However, some critical technology issues had to be taken into account. This includes the alignment of the shadow mask for metallization by 200 µm deep etched V-grooves at the wafers in combination with pyramids at the mask and the vertical FET fabrication itself. The following five lithography levels are required: mask for shadow mask alignment using V-grooves, mask for drain pit patterning, implantation mask for n^+-regions, mask for contact windows and finally the mask for anisotropic deep silicon etching of mechanical released structures and isolation trenches. For connecting the drain layer, 15 µm deep V-pits were etched (KOH) and ion implanted in order to carry the electrical potential to the wafer surface. A pn junction is used for electrical isolation. In order to avoid any damaging during the following lithography step caused by these pits (spin-on processing) special design rules and viscous resist are used, respectively.

4 EXPERIMENTAL RESULTS

The measurements were carried out on wafer level and on single vertical FET's. A HP 4062 UX process control system with a HP 4142B modular DC source / monitor was used to bias the gate, drain, source and substrate of the vertical FET.

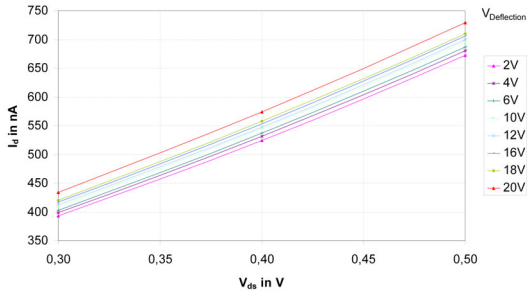

***Figure 5**. I-U-characteristic depending on deflection voltage*

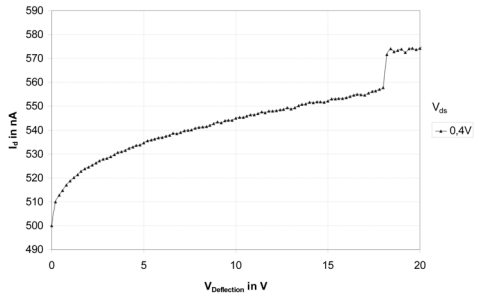

***Figure 6.** Transfer characteristic at V_{ds}= 0,4 V and V_{gs}=5 V*

5 SUMMARY

The main advantages of the vertical FET with respect to capacitive sensor systems are:

- higher signal-to-chip size ratio
- simplifications of the signal conditioning circuitry
- low impedance sensing technique
- the sensing element is an "active sensor"
- mechanical movement and output sensor signal are in phase.

The dynamic behaviour of the structure will be examined.

6 REFERENCES

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