THICK SINGLE CRYSTAL Si LATERAL RESONANT DEVICES INTEGRATED WITH A CONVENTIONAL CIRCUIT PROCESS

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ABSTRACT

A new, simple process has been developed which integrates thick single crystal Si lateral resonators with a standard circuit process. The process allows for the fabrication of mechanical devices as thick as 11 µm to be integrated with any conventional integrated circuit process with the addition of only a single masking step. Single crystal Si resonators have been fabricated and tested with working metal oxide semiconductor (MOS) transistors on the same chip. An 11 µm thick, 500 µm long clamped-clamped beam comb driven resonator is demonstrated with a resonant frequency of 32.3 kHz and an amplitude of vibration of 7.1 µm in air.

INTRODUCTION

One of the drivers in the micromachining industry is the ability to integrate mechanical structures with circuits. This can be used in sensors to detect a small signal produced by a sensor without having to take the signal off chip where parasitics are large. The ability to fabricate resonators and sensors with circuitry on the same chip, allows much more sensitive devices to be fabricated and small signals to be amplified and conditioned in a single device. There are products currently in volume production which utilize sensors with signal conditioning circuitry on the same ship. Most of these processes are surface micromachining processes in which the structural material is polysilicon and its thickness is limited. Also stress must be carefully tailored in the polysilicon film. Single crystal Si has excellent mechanical properties and thus it is a desirable material with which to fabricate mechanical devices. A process has been developed which combines the excellent properties of thick single crystal Si mechanical devices with the advantage of on chip circuitry.

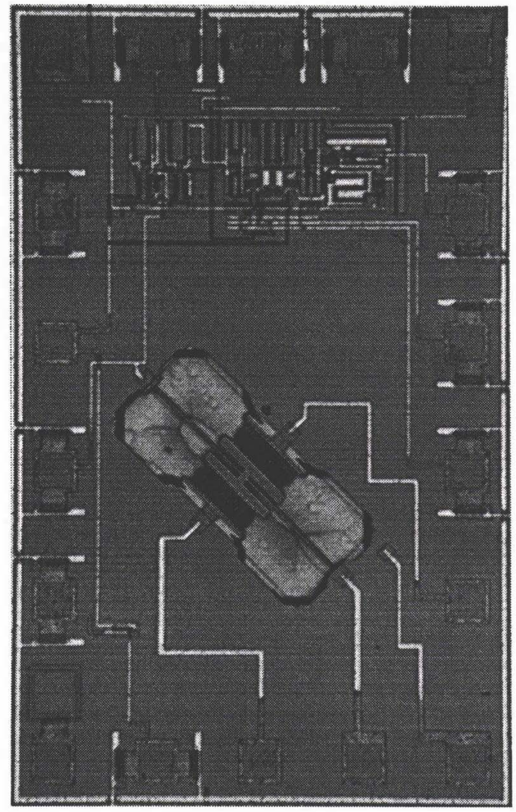

Figure 2. Photograph of the clamped-clamped beam resonator integrated with the transimpedance amplifier.

EXPERIMENTAL DETAILS

A schematic of the process flow used to fabricate the devices is shown in Fig. 1. [1,2] First, a deep B diffusion was selectively performed which will determine the thickness of the resonator. Devices can be fabricated

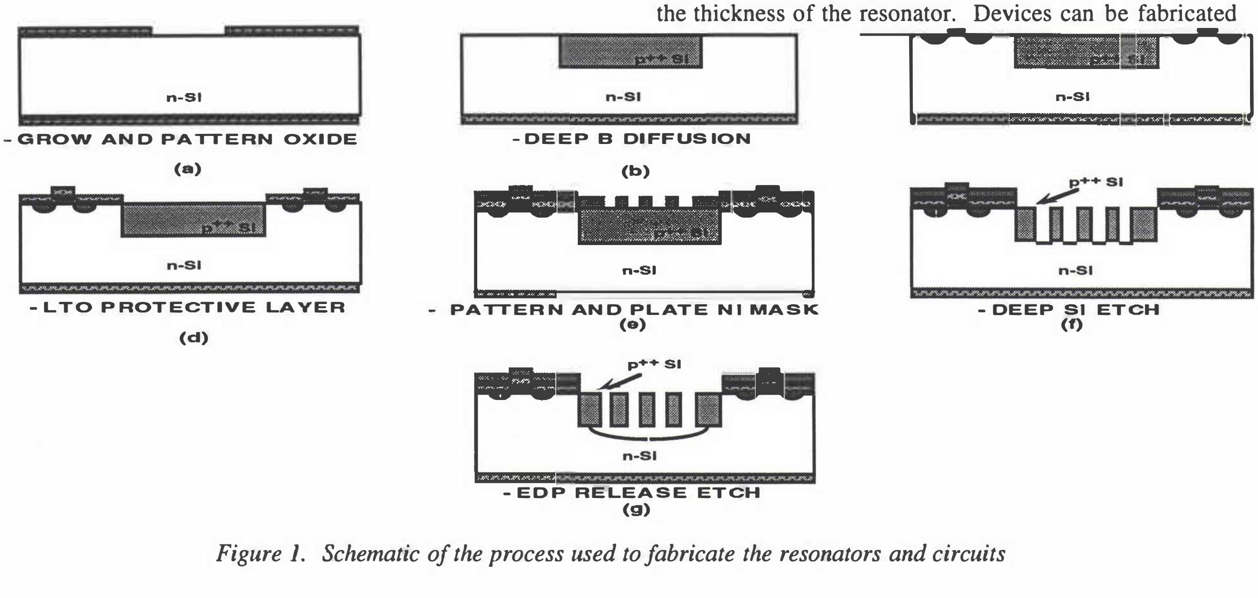

Figure 1. Schematic of the process used to fabricate the resonators and circuits

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with any thickness up to the available thickness of a diffused B layer which is about 15 μm. Next, the standard circuit processing is done. Since the circuit processing is totally independent of the resonator processing, any circuit process can be used. A low temperature oxide was then grown on top of the circuit to serve as a passivation layer, and to later protect the transistors from an ethylenediamine pyrocatechol (EDP) etch. A Ni mask was electroplated through a photoresist mold which served as the etch mask for the dry etch. A dry etch in an inductively couple plasma (ICP) source using 250 W source power, 70 W stage power at 5 mTorr with 20 sccm of Cl_2 flow and a source to sample distance of 8 cm was performed. This etch defines the resonators and high aspect ratio elements can be achieved with fast etch rates in the ICP source. An EDP etch was done in order to undercut and release the structure. The EDP solution did not etch the heavily B doped Si structure. Finally, the Ni mask was removed. A photograph of the die with a clamped-clamped beam resonator and a transimpedence amplifier is shown in Fig. 2.

The transimpedance amplifier detection circuitry was fabricated using a 3 μm, 2-poly, 1-metal BiCMOS process at the University of Michigan. The amplifier has a measured 3 dB frequency of 100 kHz. To minimize power consumption, the transistors are operated in the subthreshold regime, with a bias current of less than 250 nA. For a 0-5 V rail-to-rail supply, the power dissipation is approximately 1.25 μW. The characteristics of an NMOS transistor was measured after the EDP release step and the I-V curves are shown in Fig. 3.

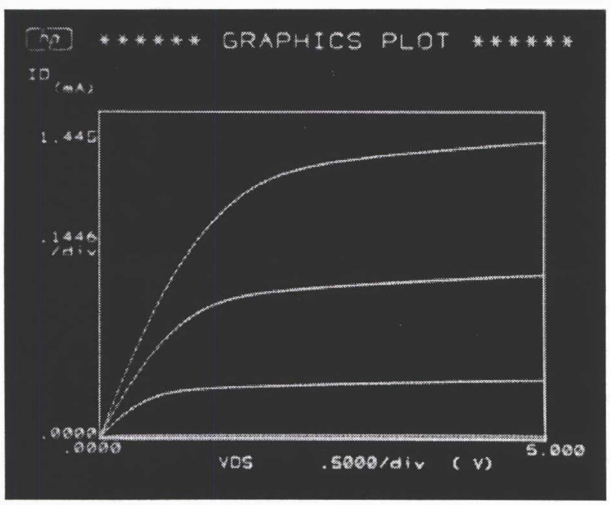

Figure 3. NMOS I-V curves for a transistor on the same die as the measured resonator after structure release.

The single crystal Si clamped-clamped beam comb drive resonator shown in Fig. 4 has been fabricated and tested in order to validate the integrated process. Figure 5 shows a close-up of the comb drive used to drive and sense movement in the resonator. The resonant beam was 11 μm thick, 5 μm wide, and 500 μm long with 3 μm wide comb fingers and 3 μm wide gaps between fingers. The resonant frequency of the devices was measured to be 32.3 kHz and a maximum amplitude of vibration of 7.1 μm was measured at the resonant frequency.

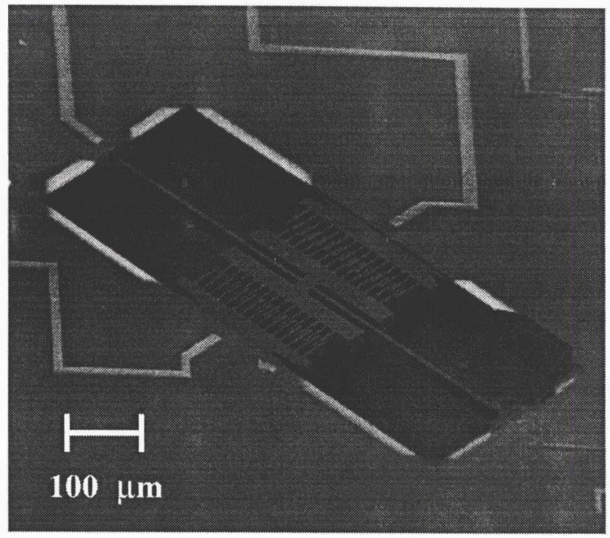

Figure 4. Micrograph of 11 μm thick, 500 μm long released resonator with 3 μm wide combs and 3 μm wide gaps.

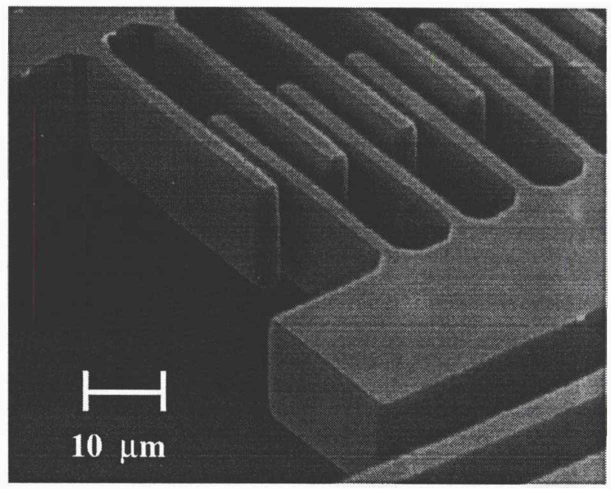

Figure 5. A close-up of the electrostatic comb drive with 3.0 μm wide fingers and 3.0 μm wide gaps.

SUMMARY

A simple process has been developed in which an 11 μm thick single crystal Si resonator has been integrated with BiCMOS circuitry.

REFERENCES

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[2] J. W. Weigold and S. W. Pang, "A New Frontside-Release Etch-Diffusion Process for the Fabrication of Thick Si Microstructures", Transducers '97, Chicago, IL, pp. 1435-1438, 1997.