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# Si-piezoresistive microcantilevers for highly integrated parallel force detection applications

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**Abstract**

We have developed an integrated and compact microdevice consisting of piezoresistive microcantilevers with a dedicated electronic read-out. This microdevice designed for force sensor applications can also be used in atomic force microscopy for parallel operation without an optical detection scheme. The system features a 1.25 V/μm resolution with 10 mV noise.
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*Keywords:* Piezoresistivity; Microcantilevers; Integration; Parallel detection

## 1. Introduction

Cantilever-based sensors [1–2] usually use the deflection of the cantilever to measure the force or surface stress. Cantilever bending can be detected using various kinds of read-out systems including in particular the optical beam deflection technique. A laser beam is focused on the cantilever backside and reflected onto a sensor. A change in the cantilever's deflection can then be detected. However, this technique calls for a precise alignment of the external laser and sensor. Also the use of an optical system requires a sophisticated experimental set-up (due to environmental conditions as in a solution, for example). For parallel operation when cantilever arrays are used, this approach is also known to be very challenging.

The disadvantages of an external sensor system may be overcome by integrating the sensor on the cantilever. Most solutions are based on piezoelectric [3–4], capacitive [5] and piezoresistive [6–9] schemes. We selected the piezoresistive approach, since it can easily be adapted to different environmental conditions (temperature, liquids, . . .) and owing to its compatibility with external electronics. Here the aim is two-fold: (i) to design and fabricate highly sensitive piezoresistive cantilevers and (ii) to develop a dedicated electronic read-out for highly integrated parallel force detection applications.

## 2. Microcantilever fabrication

Fig. 1 summarizes the different steps in the fabrication of piezoresistive microcantilevers. Fabrication is based on standard micromachining techniques using a SOI wafer [10]. First of all, the piezoresistor is placed on the top Si layer (Fig. 1(a)). A method has already been proposed for the formation of ultrathin piezoresistive layers by implantation of germanium and $BF_2$ [10].

Reduction of thickness of the piezoresistor leads to a very precise detection of cantilever deflection. Ge is implanted with energy of 60 keV and a dose of $5 \times 10^{14}\ cm^{-2}$ in order to obtain the Ge preamorphized layer which avoids the channeling effect during boron implantation. $BF_2$ is then implanted with energy of 15 keV and a dose of $1 \times 10^{16}\ cm^{-2}$. Owing

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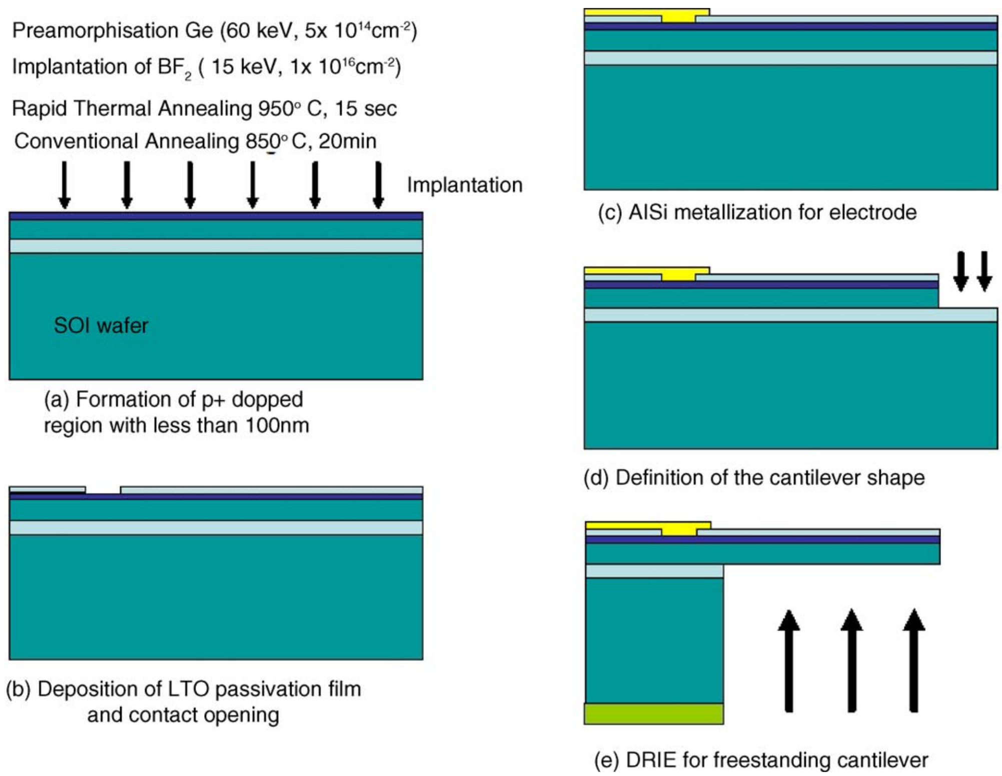


Fig. 1. Fabrication process.

to the heavier $BF_2$ molecule relative to B, the thickness of the p+ doped region is reduced. Then rapid thermal annealing is performed to minimize boron diffusion while recrystallization of the amorphized layer occurs. This is followed by a conventional annealing at 850 °C for 20 min.

Thus, ultrashallow p+/n junctions in single crystal Si with a thickness less than 200 nm can be obtained. The piezoresistor is passivated with a low temperature oxide (LTO) and contact opening is achieved (Fig. 1(b)). AlSi deposition by sputtering for electrode and metal annealing with 450 °C can be performed (Fig. 1(c)). Top Si layer is etched using reactive ion etching to pattern the cantilever shape (Fig. 1(d)). Finally, deep reactive ion etching on the back side and etching of the intermediate $SiO_2$ layer using reactive ion etching lead to the creation of freestanding cantilevers (Fig. 1(e)).

V-shaped piezoresistive microcantilevers are fabricated as shown in the SEM image of Fig. 2. Cantilever length and thickness are 200 and 5 μm, respectively. Each cantilever leg is Si⟨1 1 0⟩ oriented, since the Si⟨1 1 0⟩ direction exhibits the highest piezoresistive coefficient in the p-doped Si.

Using this method, arrays of four cantilevers have been obtained including a fifth microcantilever used as reference during measurement. Indeed, this cantilever is never in contact with the surface as shown Fig. 3.

These V-shaped cantilevers are devoid of tip. They are placed in contact with the surface using a certain angle so that the cantilever end (bottom of the V) is the only area in contact with the substrate.

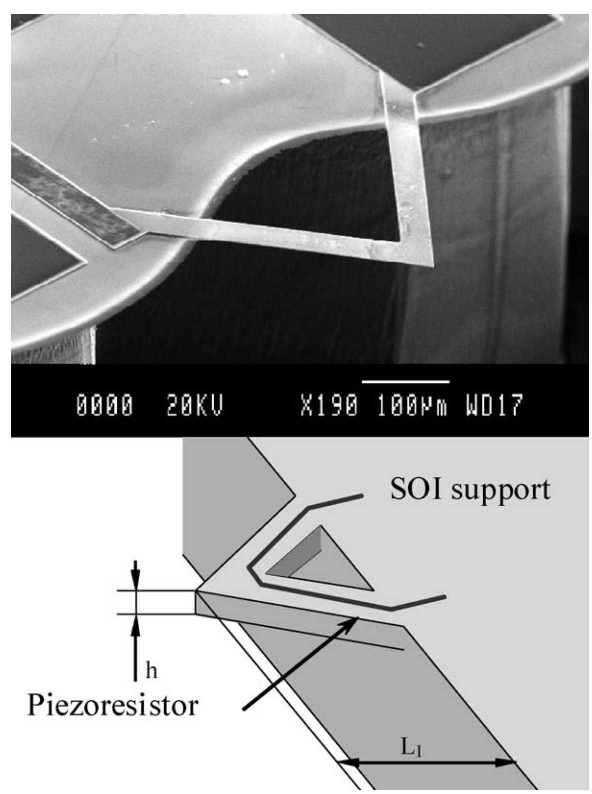


Fig. 2. (a) SEM image of the piezoresistive cantilever array. (b) Schematic design: length ($L_1$) 200 μm, thickness ($h$) 5 μm.

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