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Design and Fabrication of MEMS U-Shaped Cantilever

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Abstract*: *MEMS are used in acceleration, flow, pressure and force sensing applications on the micro and macro levels. The fundamental part of every sensor is the transducer, which converts the measured quantity of interest into an interpretable output signal. The most prominent transducer is the piezoresistive cantilever, which translates any signal into an electrical signal. This paper presents the design and fabrication of a U-shaped cantilever with enhanced sensitivity and stiffness, which yields better results than other cantilevers. The simulation results of the cantilevers are designed using COMSOL software. MEMS technology becomes more affordable, better, and easier to fabricate in increasing quantities. Each layer of the fabrication process is quite complex, and the final manufactured product will be tested and used for high-end applications.

Keywords*: *MEMS, Fabrication, Cantilever, Comsol

I. INTRODUCTION

The MEMS biomass sensors are used for detecting weight ranges from picograms to femtograms. However, these molecules must be sensed using a cantilever with increased sensitivity and stiffness. Piezo resistance is a characteristic of conductive and semiconductive materials attributed to the change of the electrical resistance with an applied stress. Piezoresistive cantilevers have been successfully commercialized especially in applications such as accelerometers AFM probes for scientific and sensing modules. The cantilever operates in both static and dynamic modes. The static mode focuses on the change in resistance, and the dynamic mode stresses the change in resonant frequency. Starting with the deposition of the fabrication process, the first step involves wafer deposition of a polysilicon layer, which is then exposed to mask light and chemicals to etch holes. The next layer is sacrificial and is also exposed to masks, light, and chemicals. The light is used to harden or soften certain parts of the layer, allowing the etching process to etch the unwanted parts and create the desired shapes.

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II. LITERATURE

Research in MEMS is an interdisciplinary activity involving various engineering disciplines, including mechanical engineering, materials science, electronics, and instrumentation. It is an integration of mechanical and electronic systems on the same micro-scale chip. MEMS systems are replacing conventional systems due to their unique advantages, including IC technology with integrated multi-functionality, precision, and improved performance, as well as batch fabrication, which leads to reduced manufacturing costs and time. Miniaturization which results in portability, ruggedness, low-power consumption, developed on a mass scale, easily maintained and repaired, and less harmful to environment. Researchers in MEMS focus on various fields, including design, materials, processing, fabrication, testing, and calibration. Microcantilevers are popular as sensing elements in bioMEMS applications. A bio-MEMS sensor consists of a bio-receptor and transducer. A biosensor utilizes chemical and biological reactions to detect and quantify a specific analyte. A biosensor, which uses mass-based transduction, is called a mass sensor [1]. Mass sensors are used to detect tiny masses of biomolecules, such as proteins, viruses, or even parts of DNA, in the range of femtograms (10^-15 gm) to zeptograms (10^-21 gm). In all applications, one of the key points for a successful solution to the problem is the availability of a detector with high sensitivity, selectivity, and reproducibility for the chemical and biochemical parameters of interest. The sensitivity or minimum detectable mass depends on the ratio between the mass and the resonant frequency of the beam. Generally, the resonant frequency increases and the mass decreases when the dimensions are reduced. Thus, a straightforward approach to enhance sensitivity is to reduce the dimensions of the beam. In microcantilever biosensors, the cantilever transduces the recognition event from its receptor-immobilised surface (for example, a DNA probe and an antigen or antibody) into a mechanical response (for example, static displacement and resonance frequency). Microcantilever provides an alternative technology that overcomes this limitation. One face of the cantilever is coated with a functionalizing layer, which is highly specific to a particular analyte. This layer acts as the sensing element. When the cantilever is brought into contact with the corresponding analyte, the interaction between the functionalizing layer and the analyte causes a change of free energy, which results in a change of surface stress. The difference in stresses between the functionalized and non-functionalized layers causes the cantilever to deflect.

Thus, the cantilever transduces a chemical reaction into a mechanical response. Measurement of this deflection provides a rapid indication of the analyte concentration.

III. FINITE ELEMENT ANALYSIS OF U-SHAPED PIEZORESISTIVE CANTILEVER

A U-shaped cantilever is designed with insulation layers of the following dimensions.

U -shape	Length (µm)	Width (µm)	Thickness (µm)	Material
Layer 1	200	100	0.65	SiO2
Layer 2	200	100	0.7	PolySi
Layer 3	200	100	0.65	SiO2

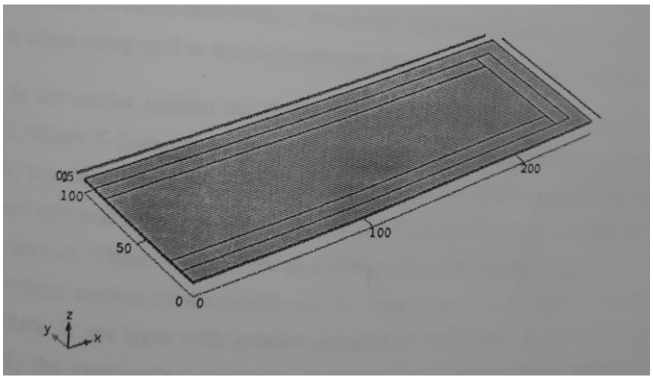

Fig.1: U-shaped cantilever

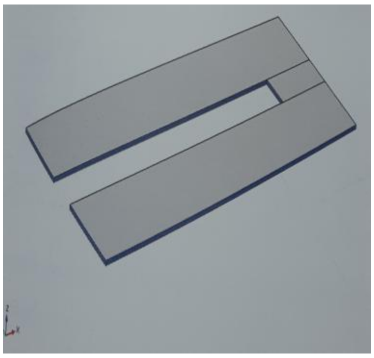

Fig.2: Simulated U-shaped cantilever

The width of 100µm includes the air gap between the two legs. The proposed U-shaped cantilever has three layers. The middle layer is the sensing piezoresistive layer. In contrast, the top and bottom layers serve as the sensing surfaces, on which the analytes are deposited to create deflection in the cantilever, producing stress that can be sensed with greater sensitivity and stiffness [2]

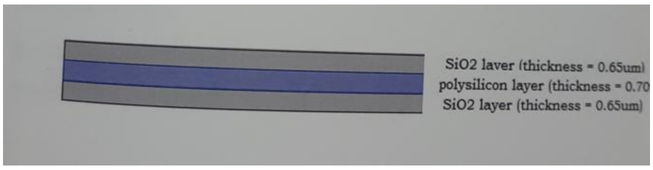

Fig.3: Dimensions of the cantilever

IV. FABRICATION

Microcantilever fabrication involves a process that includes wafer cleaning, wet oxidation, Lithography, oxide etching, and silicon etching.

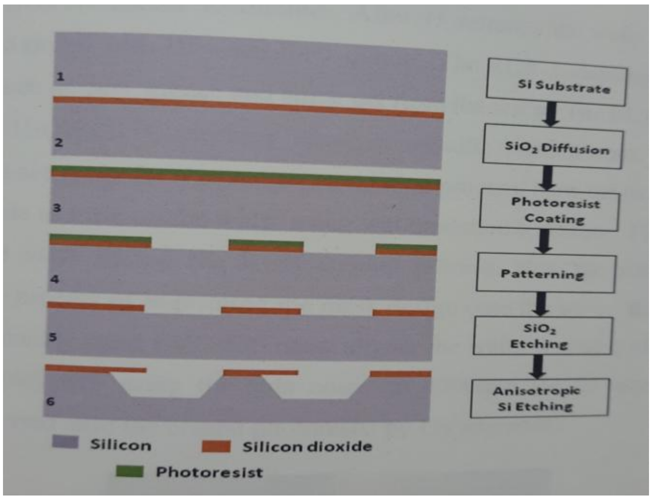

Fig.4: Fabrication process

The first step in microcantilever fabrication is wafer cleaning. Initially, the wafer is cleaned in Deionised water, then it is placed in RCA-I solution for 15 minutes. After 15 minutes, the wafer is removed from the solution and rinsed with DI water for 1 minute. The RCA-I cleaning removes surface contaminants, such as dust, grease, and silica gel, from the water. The RCA-II cleaning removes metallic contaminants from the wafer. Now the wafer is ready for the thermal wet oxidation process. A 2µm-thick oxide layer is formed on the wafer using the wet oxidation technique. This oxide layer is used as a hard mask during the KOH etching process. Now the wafer is ready for lithography, the process of imprinting the mask design onto the wafer [3]. Before placing the wafer onto the double-sided EVG620 mask aligner, the wafer is coated with positive-tone photoresist Shipley 813 using a spin coater at 400 rpm for 40 seconds. The mask pattern is transferred onto the coated photoresist by UV exposure.

The celvin software is used for imprinting the mask structures.

Fig.5: Mask Imprinting

The pattern is then developed in an MF26A developer solution for 1 min and rinsed with DI water, followed by nitrogen drying. The released microcantilevers can be observed under a high-resolution microscope [4].

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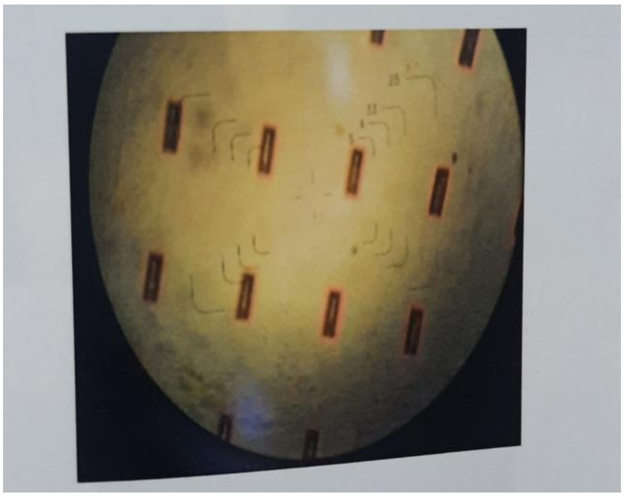

Fig.6 Cantilever structures

The mask Alignment set-up is as follows:

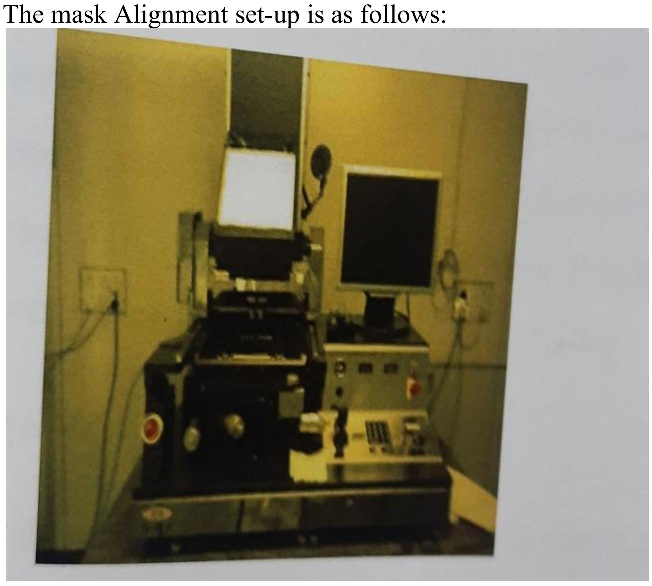

Fig.7 Mask Alignment

HWCVD is a new technique which is used to deposit a thin layer of polycrystalline silicon on a substrate [5]. The reactant gases Silane, diborane and hydrogen thermally decomposed at the surface of a resistively heated filament, whose temperature range is 1500-2000ºC, to form radicals. The recipe used in HWCVD is as follows.

Base pressure = 1.76e^{-6}

Gas pressure = 1.1e^{-1}

Substrate temperature = 300ºCelsius

Filament temperature = 1850º Celsius

Ratio of gases SiH4:B2H6:H2= 1:5:10

Voltage = 22.7v

Current = 13.7Amp

Process time = 30 min.

Lithography was used to transfer the pattern onto the whole wafer. After that, dry cleaning was done in STS RIE to remove polysilicon from the unwanted region.

Gases used SF6 = 25sccm

Chamber pressure = 100mtorr

RF power = 150 watts

Etching time = 30 seconds

The fabricated cantilever was released by removing the sacrificial layer with BHF 5:1. While releasing the cantilever, a colour change was observed. Additionally, to verify the etching results, a contact angle measurement was performed on the sample. In contact angle measurement, the angle was found to be greater than 90º, which means that SiO2 is obliterated, indicating a hydrophobic nature.

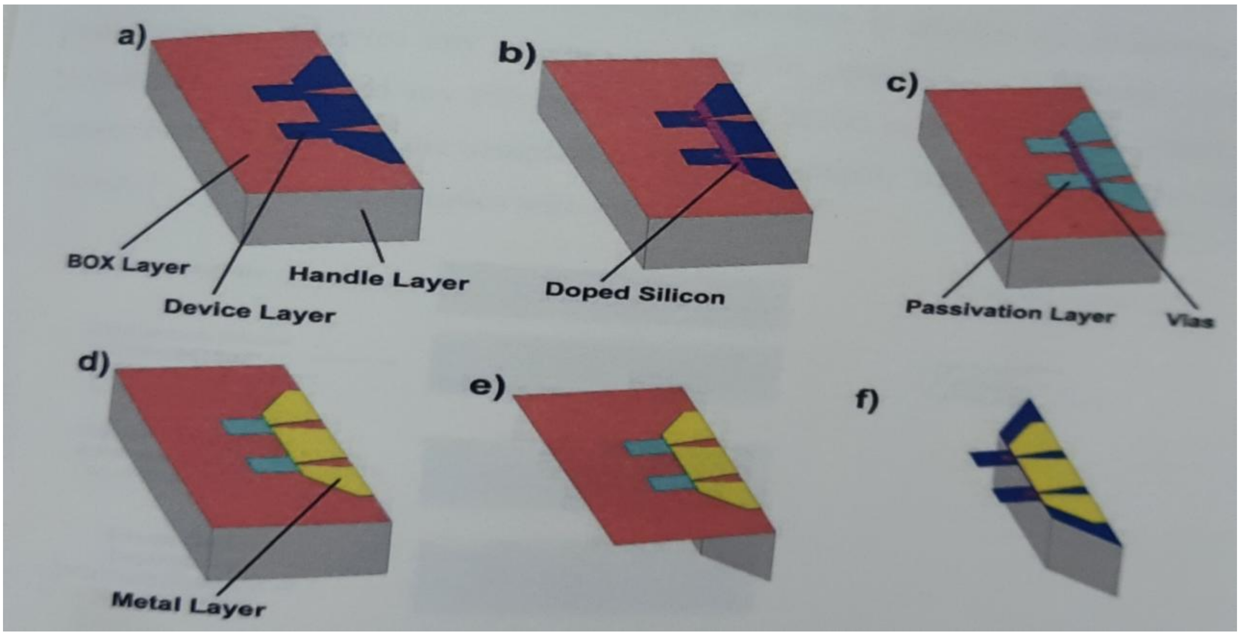

Fig.8 Lithography

V. CONCLUSION

This paper presented the design and fabrication of the cantilever. The design of a U-shaped cantilever is simulated using COMSOL software, and it is observed that U-shaped cantilevers with three layers have given enhanced sensitivity. The change in resistance due to the stress-induced strain has caused the cantilever deflection. The cantilever is fabricated using a different process, and these cantilevers can be utilised in various applications.

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Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	If applicable and having more than 01 author: All authors have individual partnerships in this article. The first author has worked on the design of cantilevers, the second author has worked on fabrication technologies, and the third author has worked on mathematical aspects of the cantilever.

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Dr. K. Durga Aparna has completed her Ph.D. from Andhra University under the DST Women Scientist Scheme. Her area of research is in MEMS. She has attended a hands-on training workshop at IIT Bombay. She has attended numerous seminars and training sessions at various institutions and has published papers in several research journals. She has 13 years of teaching experience in the Department of Electronics, Instrumentation, and Physics. She is currently working as a Lecturer in the Department of Electronics and Physics at PRISM Degree College, Visakhapatnam.

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