Fabrication of MEMS/NEMS Cantilevers with different material coatings characterization using SEM and LDV

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ABSTRACT

In the present work, we have fabricated two different types of MEMS/NEMS Cantilevers and done characterization using SEM and LDV analysis for different design metrics. Identifying and recognizable proof of Nano cantilevers are working an imperative part works in the front line world, especially in the medicine, science, normal distinguishing applications, biomedical and in Nano equipment building. Examination and reaction of the cantilever is being shown in Nano cantilever by assembling it adaptable. Recently, investigation and disclosure of Nano cantilever properties using nano materials, analytes has experienced consideration taken and has transformed into a basic issue in the setup and production of Nano cantilevers. One of the ways to deal with handle this analytes with investigation stage issue is to arrange and fabricate splendid, adroit, and flexible by working suitably by usage of Nano advanced materials, analytes; else they may impact its resonation repeat, change in resistance with time, affectability, and its extraordinary working is outlined. A Piezoresistive nano cantilever is fabricated based nano-composite. Its surface is further coated with permeable polyvinylpyridine as a detecting and functional layer. The sensor demonstrated a most extreme Resonance frequency reaction of 1400 KHz toward change in resistance 98kΩ. The further micro-cantilevers feature a special coating of 6-Marcaptonicotonic acid (6-MNA) on one side of the cantilever which leads to a selective reaction of the target analyte molecules with the functionalized cantilever surface. In the second case the Resonance frequency reaction of 1450 KHz toward change in resistance 89kΩ. High Sensitivity values change in resistance relies on upon the analyte substance and material coating separately are accomplished which is useful in detecting applications.
Keywords: MEMS/NEMS, fabrication, materials coatings, analytes, omnicant

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1. Introduction

Nano cantilever sensors as of late utilized for physical, concoction and natural detecting. Nano cantilevers can be utilized for both static and element estimations in fluid or in gas stage. These sensors have a few preferences in the region of therapeutic, especially for the perception of illnesses, detecting of point varieties, blood glucose observing and detecting of compound and organic fighting operators. These sensors have numerous advantages over the current diagnostic methods as far as great affectability, minimal effort, general methodology, low analyte necessity (in µl), non-unsafe strategies and quick reaction. Besides, the nano innovation has been created in the two decades for the manufacture and utilization of cantilevers for identification applications, in this manner giving more significance to MEMS/NEMS. The ebb and flow market has definitely expanded as far as possible up to the specific that analysts can now envision the quantity of atoms. In view of the capacity of extortionate throughput investigation of analyte and ultra-delicate discovery, the present innovation seizes gigantic undertaking for the up and coming era of little and exceedingly touchy Piezoresistive Nano cantilever sensors.

In Piezoresistive nano cantilevers, piezoresistor has been installed in them, which displays an adjustment in resistance when the cantilever twists. By measuring the adjustment in resistance utilizing an aligned electrical circuit, cantilever avoidance can be resolved. The identification operation methodology of nano cantilevers would be predominately sorted in view of their standards in believer the acknowledgment development into Nano mechanical movement. Essentially there are three methodologies of operation, for example, static technique, dynamic strategy and warmth strategy (Lang et al., 2010). In static mode, the bowing of the Nano cantilever upon the sub-atomic adsorption is measured. In element mode, the reliance of full recurrence of the nano cantilever on the mass of the nano cantilever is misused. The warmth mode, gives favorable position of the bimetallic or bimorph impact that provides for a bowing of a biomaterial nano cantilever with change in various temperature.

Piezoresistive cantilevers were initially created for AFM imaging and were later utilized for estimation of warm extension of alpha uranium (Boisen et al., 2011). Additionally uses of piezoresistive nano cantilevers incorporate discovery of thanol, glucose and saccharides for checking merged bioprocessing, gas detecting (Boisen et al., 2011), identification of unstable vapors in air (Seena et al., 2011) and location of protein markers in blood (Seena et al., 2009). These cantilevers may likewise be incorporated with CMOS circuits for sign enhancement and handling. Nano cantilever sensor innovation has been consistently developing for the most recent decade. Nano cantilever sensors depend on their avoidance to show detecting. This segment examine about the thought for the mechanical and vibration reaction of Nano cantilevers in the bowing development when utilized as sensors. The present creation accomplished a huge information in Nano cantilever bowing because of surface anxiety changes. Expanding surface anxiety, which is brought about by common on the nano cantilever outside serves to comprehension the basic surface science? The present work thought is isolated into the a few methodologies of nano cantilever diversion, upward and descending that are utilized as a part of discovery applications.

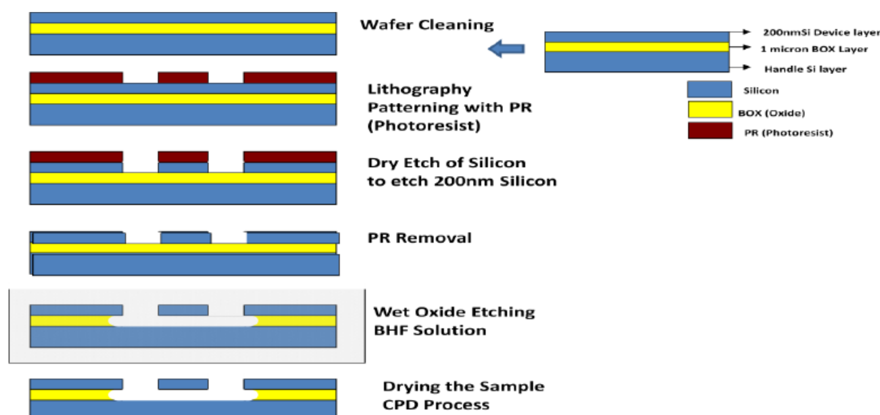

Fig 1: Fabriation steps

There are different steps in the fabrication of cantilever. First in lithography has: Wafer cleaning, dehydration, photo resist application, spin coating, soft baking exposure, development and hard-baking. Then, for silicon cantilever, after lithography has following steps: Dry etch, PR removal, Wet etch, CPD process.

In lithography:

(a) Wafer cleaning in clean room: SOI Wafer is taken as a substrate of N type <100> type. Silicon has layer of 1 micron of oxide and then 2nm Si layer on the oxide. For removal of organic contamination cleaning process is followed by two steps: (i) RCA 1 (ii) RCA 2. (iii) HF

RCA 1: H_2O: NH_4OH: H_2O_2:: 5: 1:1

RCA 2: H_2O: HCl : H_2O_2 :: 6: 1: 1

HF: H_2O:: 1:50

First dip, wafer in RCA 1 solution at 75° c for 10 min. This base-peroxide mixture removes organic residues and is also very effective in removing particles from the surface. Then, dip in HF solution, wash with DI water and dry it with nitrogen gas. Then again dip in RCA 2 solution and keep it for 10 min. at 75° c. This treatment effectively removes the remaining traces of metallic (ionic) contaminants. Then again dip in HF solution, wash with DI water dry it with nitrogen gas.

(a) Dehydration

The cleaned wafer is kept over hot plate for five minutes at a temperature of 250° c for dehydration which removes any water particles that has remained on the surface.

(c) Spin Coating:

Spin coating is a procedure used to deposit uniform thin films to flat substrates. Usually a small amount of coating material is applied on the center of the substrate, which is either spinning at low speed or not spinning at all. The substrate is then rotated at high speed in order to spread the coating material by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner. Rotation is continued while the fluid spins off the edges of the substrate, until the desired thickness of the film is achieved. Higher the angular speed of spinning, the thinner the film. The thickness of the film also depends on the viscosity and concentration of the solution and the solvent.

We applied positive Photoresist AZ5214 over a cleaned 2-inch Silicon Wafer for spin coating. Then we set the rpm of the spin coater initially at 500 rpm for 5 secs, then, raised it to 4000 rpm for 40 secs and again ramped it down to 500 rpm for 5 sec. The ramping of spin coater's rpm is done in order to minimize the fall off of the PR. As a result of which we achieved 1.4 um of PR thickness above the substrate.

There are two types of photoresist: positive photoresist and negative photoresist.
For positive resists, the resist is exposed with UV light wherever the underlying material is to be removed. In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material.

Negative resists behave in just the opposite manner. Exposure to the UV light causes the negative resist to become polymerized, and more difficult to dissolve. Therefore, the negative resist remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. Masks used for negative photoresist, therefore, contain the inverse (or photographic "negative") of the pattern to be transferred.

(d) Soft Bake

PR coating is followed by a soft bake, which is done by heating the substrate to 110 C for 20 min in a furnace for the following reasons:

- Drive away the solvent from the spun-on resist
- Improve the adhesion of the resist to the wafer and
- Anneal the shear stresses introduced during the spin-coating.

(e) Exposure (mask aligner)

After a wafer has been coated with photo resist and subjected to soft baking, it has to undergo exposure to UV radiation that will produce the predefined pattern image on the resist. The pattern is formed on the wafer using a mask, which defines which areas of the resist surface will be exposed to radiation and those that will be covered. The chemical properties of the resist regions struck by radiation change in a manner that depends on the type of resist used. Irradiated regions of positive photo resists will become more soluble in the developer, so positive resists form a positive image of the mask on the wafer. Negative resists form a negative image of the mask on the wafer because the exposed regions become less soluble in the developer.

The exposure is done with EVG of 365nm. Its parameters are: Wavelength: 365 nm, Mode: hard contact + vacuum, Energy: 45mJ/cm2

(d) Development:
It is the process step that follows resist exposure, is done to leave behind the correct resist pattern on the wafer which will serve as the physical mask that covers areas on the wafer that need to be protected from chemical attack during subsequent etching, implantation, lift-off etc. The development process involves chemical reactions wherein unprotected parts of the resist get dissolved in the developer.
The exposed wafer was then developed using developer TMAH MF 26A for 20sec. Rinse the substrate in DI water and dry the substrate with N_2 gas.

(f) Hard-Baking:
Hard-baking is the final step in the photolithographic process. This step is necessary in order to harden the photo resist and improve adhesion of the photo resist to the wafer surface. It is done by heating the developed substrate for 3min at a temp of 95° C over a hot plate. Hence, 5u cantilever are produced.

Etching:
In order to form a functional MEMS structure on a substrate, it is necessary to etch the thin films previously deposited and/or the substrate itself. In general, there are two classes of etching processes:

1. Wet etching where the material is dissolved when immersed in a chemical solution
2. Dry etching where the material is sputtered or dissolved using reactive ions or a vapor phase etchant

Isotropy and anisotropy:
When a material is attacked by a liquid or vapor etchant, it is removed isotropically (uniformly in all directions) or anisotropic etching (uniformity in vertical direction).

Wet Etching:
Wet etching is a material removal process that uses liquid chemicals or etchants to remove materials from a wafer. The specific patters are defined by masks on the wafer. Materials that are not protected by the masks are etched away by liquid chemicals.

Dry Etching:
Physical dry etching: Physical dry etching requires high energy kinetic energy (ion, electron, or photon) beams to etch off the substrate atoms. When the high energy particles knock out the atoms from the substrate surface, the material evaporates after leaving the substrate. There is no chemical reaction taking place and therefore only the material that is unmasked will be removed.

Chemical Dry Etching:
Chemical dry etching (also called vapor phase etching) does not use liquid chemicals or etchants. This process involves a chemical reaction between etchant gases to attack the silicon surface. The chemical dry etching process is usually isotropic and exhibits high selectively. Anisotropic dry etching has the ability to etch with finer resolution and higher aspect ratio than isotropic etching. Due to the directional nature of dry etching, undercutting can be avoided. Some of the ions that are used in chemical dry etching is tetrafluoromethane (CH4), sulfur hexafluoride (SF6), nitrogen trifluoride (NF3), chlorine gas (Cl2), or fluorine (F2).

Reactive Ion Etching:
Reactive ion etching (RIE) uses both physical and chemical mechanisms to achieve high levels of resolution. The process is one of the most diverse and most widely used processes in industry and research. Since the process combines both physical and chemical interactions, the process is much faster. The high energy collision from the ionization helps to dissociate the etchant molecules into more reactive species. In

the RIE-process, cations are produced from reactive gases which are accelerated with high energy to the substrate and chemically react with the silicon. The typical RIE gasses for Si are CF4, SF6.

DRIE:

The primary technology is based on the so-called "Bosch process". The first gas composition creates a polymer on the surface of the substrate, and the second gas composition etches the substrate. The polymer is immediately sputtered away by the physical part of the etching, but only on the horizontal surfaces and not the sidewalls. Since the polymer only dissolves very slowly in the chemical part of the etching, it builds up on the sidewalls and protects them from etching.

C4F8: coated to protect lateral etching during deposition cycle.
SF6: is used for etching during etch cycle.

Etch parameters:

Mask type = AZ5214, Power = 1200w, Pressure = 10 m Torr, Temperature = 15° C, RF = 100W, Kp =1500w, O2 =505 ccm, Time = 4 min
Dry etch is done using O_2 instead of removing Si.

Oxide wet etch

Wet etch is done for removing of oxide layer of Si. BHF solution is used for this process. But BOE (Buffered oxide etch) is preferred.
BOE = NH3Cl: DI :: 13:2
Etched samples are dipped in this solution for 90 min. After that solution is replaced with water by diluting.

CPD (Critical point Drying)

After oxide wet etching sample is placed in IPA medium. Then it is placed in CPD instrument. I PA is the intermediate medium. As the temperature increases, pressure increases. It goes up to 800 to 1072 psi. CO2 will the purge the IPA until the critical point is achieved. Final temperature is 40 c for CPD. To release the cantilever bean CPD is done.

2. Characterization

(a) Laser Doppler vibrometer (b) Profilometer (c) DC Probe station (d) SEM (e) AFM

2.1 Characterization of Cantilever Using LASER Doppler Vibrometer

Since exhibit cantilevers for the most part experience the problem effects of the issue of stiction, other single cantilevers were tried for vibrometer. Discharged cantilever were confirmed utilizing optical profilometer. LASER Doppler vibrometer was utilized for different portrayals identified with cantilever sensors. For this manufactured cantilever were examined utilizing microelectrodes of "Polytec, MSA500 smaller scale sys-analyzer" vibrometer. This was finished by examining one anode on SI substrate and another cathode on cantilever base. At that point sinusoidal waveform was connected to these two cathodes which offer ascent to voltage driven vibrations as a consequence of capacitive impact between cantilever body and Si substrate. Vibrations of cantilever were tested utilizing recognition of sign produced by impedance amongst episode and reflected LASER from the cantilever body. Reverberation recurrence of cantilever was observed to be 543 kHz. Time area investigation was likewise done to comprehend damping conduct of cantilever. Consideration was taken to do examining at ~ 10 times more prominent recurrence than the reverberation recurrence of cantilever.

2.2 SEM

In this investigation SEM examination has been finished with a JEOL Model JSM - 6390LV. The pictures acquired were utilized to investigation the molecule morphology, film surface geology and grain estimate. Scanning Electron Microscopy (SEM) (FIB-SEM) was performed on the manufactured and covered MEMS/NEMS cantilever gadget to examine the morphology and thickness of the Polyvinylpyrrolidone material saved on thin cantilever. Detecting portrayal is completed inside a gas chamber with controlled

substrate warming framework at 50°C temperature. In the plan denoted the outline parameters with thickness of the cantilever (348nm).

Table 1: Dimensions of the micro and nano coated PVP MEMS/NEMS Cantilever.

Type	Size
MEMS/NEMS Cantilever	Length of the cantilever = 128.5µm Width of the cantilever = 80.44 µm Thickness of the cantilever = 650nm

Fig 2: Fabricated cantilever with PVP material coating

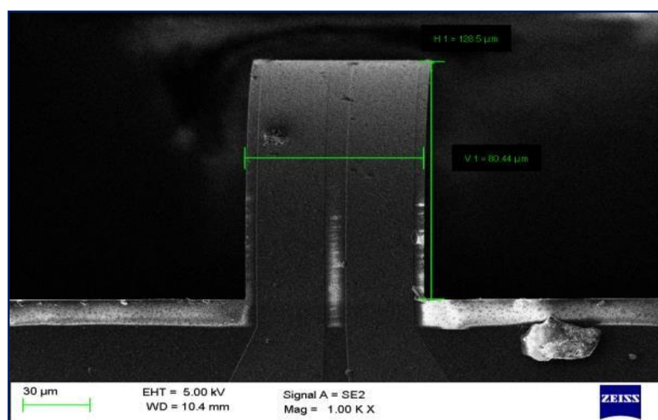

Fig: 3 SEM images MEMS/NEMS cantilever width and height

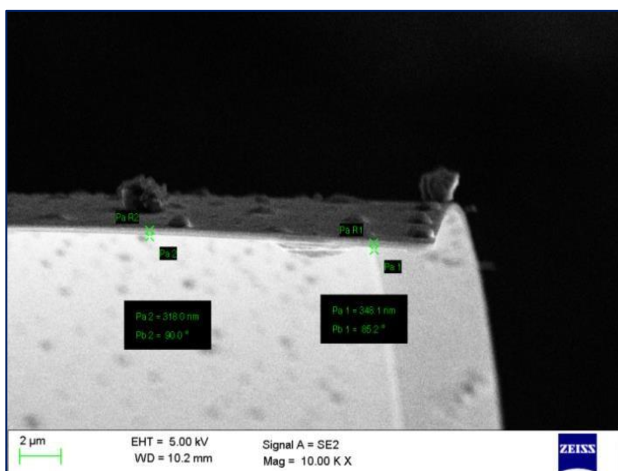

Fig 4: SEM images of MEMS/NEMS cantilever on PVP material thickness

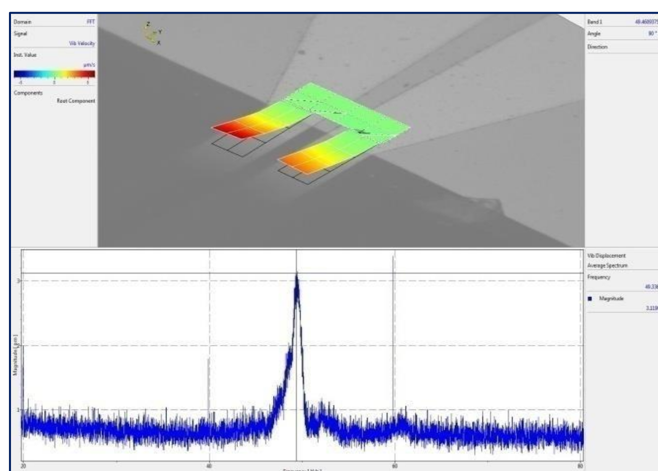

Fig 5: LDV images of micro and Nano MEMS/NEMS cantilever bending movements

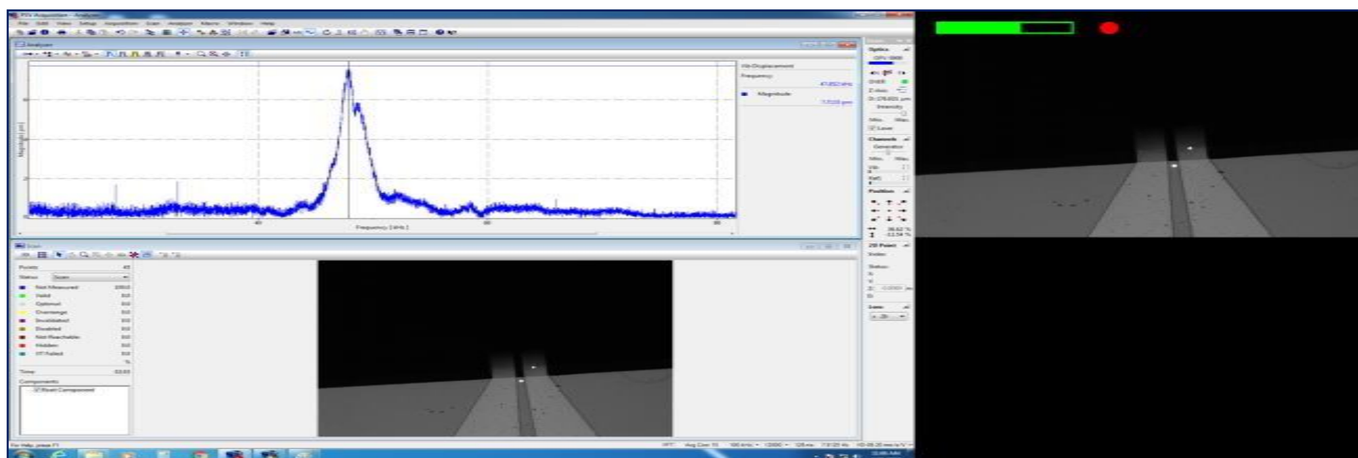

Fig 6: LDV images of micro and Nano MEMS/NEMS cantilever Resonance Frequency

Table 2: Dimensions of the micro and Nano coated 6-MNA MEMS/NEMS Cantilever.

Type	Size
MEMS/NEMS Cantilever	Length of the cantilever = 124.9 µm Width of the cantilever = 79.83 µm Thickness of the cantilever= 650 nm

Fig 7: Fabricated cantilever with 6-MNA material coating

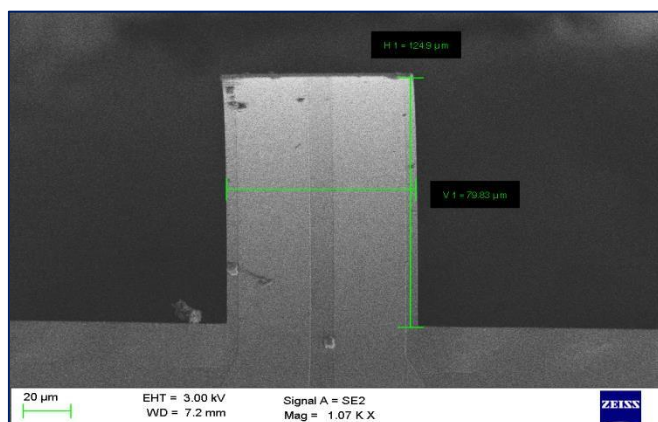

Fig 8: SEM images of MEMS/NEMS cantilever width and height

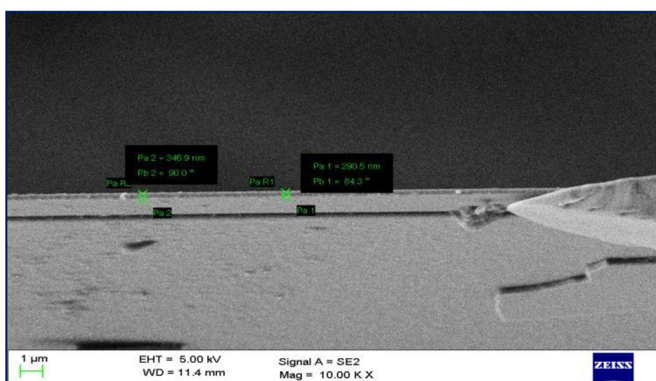

Fig 9: SEM images of MEMS/NEMS Cantilever 6-MNA material thickness

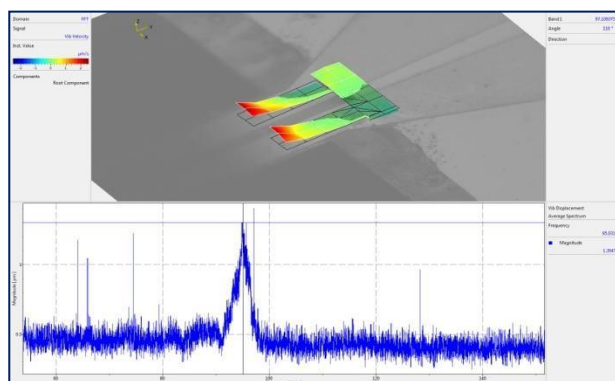

Fig 10: LDV images of micro and nano MEMS/NEMS cantilever bending movements

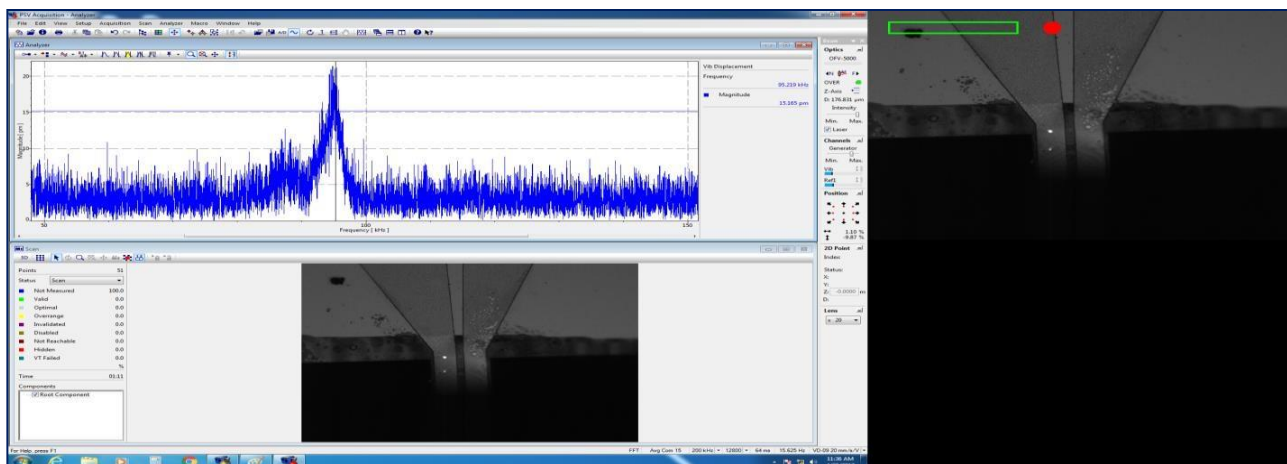

Fig 11: LDV images of micro and nano MEMS/NEMS cantilever Resonance Frequency

3. Conclusion

A nano electro mechanical cantilever was fabricated by surface micromachining convention. It was portrayed utilizing LASER Doppler vibrometer and found to have 543 kHz reverberation recurrence. The fabrication of MEMS/NEMS Cantilever with different materials showing good performance based on the characterization analysis. The sensor showed a greatest resonance frequency reaction of 543 KHz toward change in resistance 80k**Ω** with time 20 nano seconds. High Sensitivity values change in resistance relies on upon the analyte substance and material covering individually is accomplished. At last permeable Polyvinylpyrrolidone nano cantilever will give better resistance for the detection of explosives under humidity applications.

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