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Electronics

RADIO FREQUENCY MICRO ELECTRIC MECHANICAL SYSTEM (RF MEMS) AND ITS CLASSIFICATION

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ABSTRACT

The term RF MEMS refers to the design and fabrication of MEMS for RF integrated circuits. It should not be interpreted as traditional MEMS devices operating at RF frequencies. MEMS devices in RF MEMS are used for actuation or adjustment of a separate RF device or component, such as variable capacitors, switches, and filters. Traditional MEMS can be divided into two classes: MEMS actuators and MEMS sensors. The first one is a kind of moving mechanism activated by an electrical signal like Micro motor. Micro sensors are currently available for a large number of applications. Historically, owing to their ease of fabrication, these were the earliest Microsystems. Another reason for the actuators not becoming popular is that the amount of energy generated by such tiny systems does not cause much impact in the associated systems. However, it can be seen later, for microwave and millimetre wave systems, these forces are sufficient to change the properties of overall systems. Passive devices include bulk micro machined transmission lines, filters and couplers. Active MEMS devices include switches, tuners and variable capacitors.

Keywords: Dendrimer, Electronic Design Automation (EDA), fullerene, micro electro-mechanical systems (MEMS), nano-particles

INTRODUCTION

The micro electro-mechanical systems (MEMS) technology is attracting researchers towards the development of MEMS devices for radio frequency (RF) applications. RF MEMS devices have a broad range of potential applications in wireless communication, navigation and sensor systems. These are used in switches, phase shifters, signal routings, impedance matching networks, exciters, transmitters, filters, and IF/ RF receivers. Compared with the common electronic solid state switches (FET's and PIN diodes), RF MEMS based switches are characterized by very low insertion loss, low power consumption, high isolation (up to 100 GHz), low fabrication cost, and very low inter modulation. The literature shows more than 32 different types of RF MEMS with a variety of actuation mechanisms (electrostatic, magneto static, piezoelectric or thermal), contact modes (capacitive or metal-to-metal), and circuit implementation. The current paper focuses on the design and fabrication of RF MEMS switch using Shape Memory Alloys (SMA) based actuator.(El-Khoury & Mohammad A. Hotait,2004)

The paper provides a scheme to improve the performance of SMA actuation of the RF switch by allowing rapid heating and fast cooling of the SMA beam. Applying high currents results in rapid heating but requires temperature monitoring in order to avoid overheating of the SMA layer. A thermo diode temperature sensor

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with a feedback control is used to monitor the temperature of the SMA wire. As for rapid cooling, different methods are available, including water immersion, heat sinking and forced air cooling. Heat sinking is herein used to improve the cooling rate and thus provide faster switching time.(El-Khoury & Mohammad A. Hotait, 2004)

CLASSIFICATION OF RF MEMS

RF MEMS development can be classified into the following categories based on whether one takes an RF or MEMS view point:

1. RF extrinsic

RF extrinsic is the category, in which the MEMS structure is located outside the RF circuit and actuates or controls other devices in the RF circuit. In this class, one would consider the example of a tuneable micro strip transmission line and associated phased shifters and arrays. Micro strip lines are extensively used to interconnect high-speed circuits and components, because they can be fabricated by easy automated techniques.

2. RF intrinsic

RF intrinsic is the category, in which the MEMS structure is located inside the RF circuit and has both the actuation and RF-circuit function. In this class, one could consider traditional cantilever and diaphragm type MEMS which can be used as electrostatic micro switch and comb-type capacitors. With the invention of electro active polymers (EAPs), multifunctional smart polymers and micro stereo lithography, these types of RF MEMS can be easily conceived with polymer-based systems. They are also flexible, stable and long lasting. Moreover, they can be integrated with the organic thin film transistor.

3. RF reactive

RF reactive is that category, in which the MEMS structure is located inside, where it has an RF function that is coupled to the attenuation. In this class, capacitive coupled tuneable filters and resonators provide the necessary RF function in the circuit. Microwave and millimetre wave planar filters on thin dielectric membrane show low loss, and are suitable for low-cost, compact, high-performance mm-wave one-chip integrated circuits.

4. Silicon based RF MEMS

One of the earliest reported applications of silicon-based RF MEMS technology for microwave applications is in the area of surface micro machined actuators for the realization of microwave switches. These possess very high linearity, low dc standby power and low insertion loss. These switches are based on electrostatic attraction counterbalanced by suitable mechanical forces on the beam to pull the switch into the right position. This switch can be designed to present nearly 50 Ω impedance across a broad range of frequencies when closed and nearly an open circuit when there is no connection. This property makes this an attractive choice for microwave applications. Several new switch architectures have also been reported, including the air-bridge structure. This structure utilizes very high capacitance variation to achieve the switching action. This scheme, however, suffers from relatively high switching voltage requirements.

MEMs technology is also used for RF applications in the area of variable capacitors, as a replacement for varactor diodes as tuners. Here, either a lateral or a parallel plate capacitance variation can be obtained with suitable fabrication approaches. The capacitance variation in the parallel plate version is over 3:1 making them attractive for wide-band tuning of monolithic voltage-controlled oscillators (VCOs). However their range is often limited by the low-frequency mechanical resonance of the structure.

The researchers are forging marriage of nanotechnology to develop next generation RF MEMS . Recently a nanoparticle lubricant (NPL) technology was developed which was capable of improving noble metal Ohmic contact RF MEMS switching circuit power handling and lifetime ratings to meet tactical radio requirements. RF MEMS switches are expected to be a cutting edge technology for many microwave and wireless applications. But the reliability is still a challenge and the lifetime of these switches is strongly influenced by dielectric charging. By bringing in nanotechnology, the lifetime of RF MEMS can be prolonged. The future of RF MEMS is inextricably linked with the development of nanotechnology.

INTRODUCTION TO NANOTECHNOLOGY APPLICATIONS

Nanotechnology is defined as the study and use of structures between 1 nanometre and 100 nanometers in size. Nanowerk.com is a leading nanotechnology and nanosciences portal, which provides useful, and cutting-edge information from all things nano. The following applications of the nanotechnology has been discussed on this site:

The ability to see nano-sized materials has opened up a world of possibilities in a variety of industries and scientific endeavours. Because nanotechnology is essentially a set of techniques that allow manipulation of properties at a very small scale, it can have many applications, such as:

a. Drug delivery

Today, most harmful side effects of treatments such as chemotherapy are a result of drug delivery methods that don’t pinpoint their intended target cells accurately. Researchers at Harvard and MIT have been able to attach special RNA strands, measuring about 10 nm in diameter, to nano-particles and fill the nano-particles with a chemotherapy drug. These RNA strands are attracted to cancer cells. When the nano-particle encounters a cancer cell it adheres to it and releases the drug into the cancer cell. This directed method of drug delivery has great potential for treating cancer patients while producing less side harmful effects than those produced by conventional chemotherapy.

b. Fabrics

The properties of familiar materials are being changed by manufacturers who are adding nano-sized components to conventional materials to improve performance. For example, some clothing manufacturers are making water and stain repellent clothing using nanosized whiskers in the fabric that cause water to bead up on the surface.

c. Reactivity of Materials

The properties of many conventional materials change when formed as nano-sized particles (nano-particles). This is generally because nano-particles have a greater surface area per weight than larger particles; they are therefore more reactive to some other molecules. For example studies have shown that nano-particles of iron can be effective in the cleanup of chemicals in groundwater because they react more efficiently to those chemicals than larger iron particles.

d. Strength of Materials

Nano-sized particles of carbon (for example nano-tubes and bucky balls) are extremely strong. Nano-tubes and bucky balls are composed of only carbon and their strength comes from special characteristics of the bonds between carbon atoms. One proposed application that illustrates the strength of nano-sized particles of carbon is the manufacture of t-shirt weight bullet proof vests made out of carbon nano-tubes.

e. Micro/Nano Electro-Mechanical Systems

The ability to create gears, mirrors, sensor elements, as well as electronic circuitry in silicon surfaces allows the manufacture of miniature sensors such as those used to activate the airbags in a car. This technique is called MEMS (MicroElectro-Mechanical Systems). The MEMS technique results in close integration of the mechanical mechanism with the necessary electronic circuit on a single silicon chip, similar to the method used to produce computer chips. Using MEMS to produce a device reduces both the cost and size of the product, compared to similar devices made with conventional methods. MEMS is a stepping stone to NEMS or Nano-Electro-Mechanical Systems. NEMS products are being made by a few companies, and will take over as the standard once manufacturers make the investment in the equipment needed to produce nano-sized features.

f. Molecular Manufacturing

Researchers are working on developing a method called molecular manufacturing that may someday make the Star Trek replicator a reality. The gadget these folks envision is called a molecular fabricator; this device would use tiny manipulators to position atoms and molecules to build an object as complex as a desktop computer. Researchers believe that raw materials can be used to reproduce almost any inanimate object using this method.

g. The significance of nanoscale

A nano-metre (nm) is one thousand millionth of a metre. For comparison, a red blood cell is approximately 7,000 nm wide and a water molecule is almost 0.3 nm across. People are interested in the nano-scale [which we define to be from 100 nm down to the size of atoms (approximately 0.2nm)] because it is at this scale that the properties of materials can be very different from those at a larger scale.

This can be due to two main reasons. First, nano-materials have a relatively larger surface area when compared to the same mass of material produced in a larger form. This can make materials more chemically reactive (in some cases materials that are inert in their larger form are reactive when produced in their nano-scale form), and affect their strength or electrical properties. Second, quantum effects can begin to dominate the behaviour of matter at the nano-scale—particularly at the lower end—affecting the optical, electrical and magnetic behaviour of materials. Materials can be produced that are nano-scale in one dimension (for example, very thin surface coatings), in two dimensions (for example, nano-wires and nano-tubes) or in all three dimensions (for example, nano-particles).

NANO-MATERIALS

Much of nano-science and many nanotechnologies are concerned with producing new or enhanced materials. It has been 25 years since the scanning tunneling microscope (STM) was invented, followed four years later by the atomic force microscope, and this boosted nano-science and nanotechnology. Scanning probe techniques have become the workhorse of nano-science and nanotechnology research.

Current applications of nano-scale materials include very thin coatings used, for example, in electronics and active surfaces. In most applications the nano-scale components will be fixed or embedded but in some, such as those used in cosmetics and in some pilot environmental remediation applications, free nano-particles are used. The ability to machine materials to very high precision and accuracy (better than 100 nm) is leading to considerable benefits in a wide range of industrial sectors, for example in the production of components for the information and communication technology, automotive and aerospace industries.

NANO-MATERIAL SCIENCE

Nano-materials are miniaturization of materials. Some examples of nano-materials and the range of nano-science that is aimed at understanding their properties is outlined below:

NANOSCALE IN ONE DIMENSION

One-dimensional nano-materials, such as thin mms and engineered surfaces, have been developed and used for decades in fields such as electronic device manufacture, chemistry and engineering. In the silicon integrated-circuit industry, for example, many devices rely on thin films for their operation, and control of film thicknesses approaching the atomic level is routine. Mono-layers (layers that are one atom or molecule deep) are also routinely made and used in chemistry.

Engineered surfaces with tailored properties such as large surface area or specific reactivity are used routinely in a range of applications such as in fuel cells and catalysts. The large surface area provided by nano-particles, together with their ability to self assemble on a support surface, could be of use in all of these applications. It can be put to use on the small-scale, on-site production of high value chemicals such as pharmaceuticals.

NANOSCALE IN TWO DIMENSIONS

Two dimensional nanomaterials such as tubes and wires have generated considerable interest among the scientific community in recent years. In particular, their novel electrical and mechanical properties are the subject of intense research.

a) Carbon Nanotubes

Carbon nanotubes (CNTs) were first observed by Sumio Iijima in 1991. CNTs arc extended tubes of rolled graphene sheets. CNTs have assumed an important role in the context of nanomaterials, because of their novel chemical and physical properties. They are mechanically as strong as diamond, flexible and can conduct electricity well . All of these remarkable properties give CNTs a range of potential applications: for example, in reinforced composites, sensors, nanoelectronics and display devices.

b) Inorganic Nanotubes

Inorganic nanotubes and inorganic fullerene-like materials based on layered compounds such as molybdenum disulphide were discovered shortly after CNTs. They have excellent tribological (lubricating) properties, resistance to shockwave impact, catalytic reactivity, and high capacity for hydrogen and lithium storage, which suggest a range of promising applications.

c) Nanowires

Nanowires are ultrafine wires or linear arrays of dots, formed by self-assembly. They can be made from a wide range of materials. Semiconductor nanowires made of silicon, gallium nitride and indium phosphide have demonstrated remarkable optical, electronic and magnetic characteristics Nanowires have potential applications in high-density data storage, either as magnetic read heads or as patterned storage media and electronic and opto-electronic nanodevices, for metallic interconnects of quantum devices and nanodevices.

d) Biopolymers

The variability and site recognition of biopolymers, such as DNA molecules, offer a wide range of opportunities for the self-organization of wire nanostructures into much more complex patterns. The DNA backbones may then, for example, be coated in metal. They also offer opportunities to link nano- and biotechnology in, for example, biocompatible sensors and small, simple motors. Such self-assembly of organic backbone nanostructures is often controlled by weak interactions, such as hydrogen bonds, hydrophobic, or van der Waals interactions (generally in aqueous environments) and hence requires quite different synthesis strategies to CNTs, for example.

NANOSCALE IN THREE DIMENSIONS

a) Nanoparticles

Nanoparticles are often defined as particles of less than 100 nm in diameter. Nanoparticles exist widely in the natural world; for example as the products of photochemical and volcanic activity, and created by plants and algae. They have also been created for thousands of years as products of combustion and food cooking, and more recently from vehicle exhausts. Deliberately manufactured nanoparticles, such as metal oxides, are by comparison in the minority.

Nanoparticles are of interest because of the new properties (such as chemical reactivity and optical behaviour) that they exhibit compared with larger particles of the same materials. For example, titanium dioxide and zinc oxide become transparent at the nanoscale, however, are able to absorb and reflect UV light, and have found application in sunscreens. Nanoparticles have a range of potential applications: in the short-term in new cosmetics, textiles and paints; in the longer term, in methods of targeted drug delivery where they could be to used deliver drugs to a specific site in the body. Nanoparticles can also be arranged into layers on surfaces, providing a large surface area' and hence enhanced activity, relevant to a range of potential applications such as catalysts.

Manufactured nanoparticles are typically not products in their own right, but generally serve as raw materials, ingredients or additives in existing products. Nanoparticles are currently in a small number of consumer products such as cosmetics and their enhanced or novel properties may have implications for their toxicity. For most applications, nanoparticles will be fixed (for example, attached to a surface or within in a composite) although in others they will be free or suspended in fluid.

b) Fullerenes (carbon 60)

In the mid-1980s a new class of carbon material was discovered called carbon 60 (C60). Harry Kroto and Richard Smalley, the experimental chemists, who discovered C 60 named it “buckminsterfullerene”, in recognition of the architect Buckminster Fuller, who was well-known for building geodesic domes. In 1990, a technique to produce larger quantities of C60 was developed by resistively heating graphite rods in a helium atmosphere. Several applications are envisaged for fullerenes, such as miniature ‘ball bearings’ to lubricate surfaces, drug delivery vehicles and in electronic circuits.

c) Dendrimers

Dendrimers arc spherical polymeric molecules, formed through a nanoscale hierarchical self-assembly process. There are many types of dendrimer; the smallest is several nanometres in size. Dendrimers are used in conventional applications such as comings and inks, but they also have a range of interesting properties which could lead to useful applications. For example, dendrimers can act as nanoscale carrier molecules and as such could be used in drug delivery. Environmental clean-up could be assisted by dendrimers as they can trap metal ions, which could then be filtered out of water with ultra-filtration techniques.

d) Quantum dots

Nanoparticles of semiconductors (quantum dots) were theorized in the 1970s and initially created in the early 1980s. If semiconductor particles are made small enough, quantum effects come into play, which limit the energies at which electrons and holes (the absence of an electron) can exist in the particles. As energy is related to wavelength (or colour), this means that the optical properties of the particle can be finely tuned depending on its size. Thus, particles can be made to emit or absorb specific wavelengths (colours) of light merely by controlling their size. Recently, quantum dots have found applications in composites, solar ceils (Gratzel ceils) and fluorescent biological labels (for example to trace a biological molecule) which use both the small particle size and tuneable energy levels.

CONCLUSION

MEMS technology has strong ties to semiconductor processes and Electronic Design Automation (EDA) tools, such that there is a strong effort to integrate MEMS technology with IC development. This is especially true in RF MEMS design. By developing MEMS industry material property methodology, we may borrow much of the processing methodology from the IC world. Design and simulation tools are already at a highly sophisticated level. In order to complete MEMS standardization, the industry must design test structures that measure specific material properties and processing effects, derive models in suitable formats, adapt the structures to specific process flows, develop test methods for test equipment and arrange these elements in widely distributed standards. The proof of design and reliability will come as more and more wireless product designers incorporate RF MEMS within their designs and demand reliability and fabrication standards. The benefit will be both to wireless product designers in high-quality, cost-effective components and affordable functionality to the end-user.

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