# USE OF MEMS/NEMS TO SOLVE ENVIRONMENTAL PROBLEMS

**Hiroki Kuwano**
Department or Nanomechanics, Tohoku University, Sendai, Japan

**Abstract:** To date we are confronted with some difficulties of global environmental problems as well as those at the regional, neighborhood, and building level. Micro electro mechanical systems (MEMS)/nano electro mechanical systems (NEMS) will play important roles in the framework of environmental issues in many fields such as monitoring the environment, sharing information on it, and improving the fuel efficiency of automobiles, rooms, and buildings. In addition, MEMS/NEMS only need a minimum amount of material and their power consumption is usually very small. We also have to consider the power needed to manufacture them and the industrial waste they produce. I would like to show the typical life cycle of these systems and its advantages and disadvantages for the environment.

**Key words:** MEMS, NEMS, environment

## 1. INTRODUCTION

As indicated by many global warming related issues followed by the Third Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) held in Kyoto in December 1997, issues relating to the global environment have become increasingly important in recent years at the level of nations, local governments, companies, and individuals. The pace of industrial development has rapidly increased not only in advanced nations such as America, EU, Japan, but also in developing countries such as China, India, Brazil, and Russia. Beginning with the passage of COP3, the last couple of years have seen a marked strengthening of statuary measures designed to reduce greenhouse effect gases, such as $CO_2$, and thus prevent global warming. Greenhouse effect gases that lead to global warming are generated by automobiles, electric power generation systems for lighting, consumer electronics, power machinery, air conditioning, personal computer, and so on, and they also result from deforestation.

Human activities, such as mass production and consumption, as well as the expansion of the global population, are causing global warming and many related problems. These include the generation of a large amount of wastes, the disappearance of tropical rain forests, the destruction of the ozone layer, the contamination of the oceans, and acid rain. It is becoming increasingly obvious that the earth's tolerance is being exceeded and that the lives of future generations will be affected. These issues cannot be handled simply through countermeasures implemented by the companies that directly cause problems, such as the Minamata disease and the Itai-itai disease. Solving these issues requires that national governments, companies, and individuals each take responsibility.

One way of tackling a wide range of environment issue is to use MEMS and NEMS as a powerful and important tool. Furthermore, using these systems will enable companies to fulfill part of their responsibility to consume less power in their manufacturing processes and to dispose of wastes in an environmentally friendly way.

Recently, MEMS/NEMS has taken a very important position in many social systems. For instance, many kinds of micro sensors in automobiles, consumer electronics, electrical communication systems, and manufacturing and evaluation lines of industries are common. As shown in many scientific conferences, in the near future, medicine, safety and security systems, sensor network systems, and many micro energy systems, will amongst other systems make use of more sophisticated MEMS/NEMS.

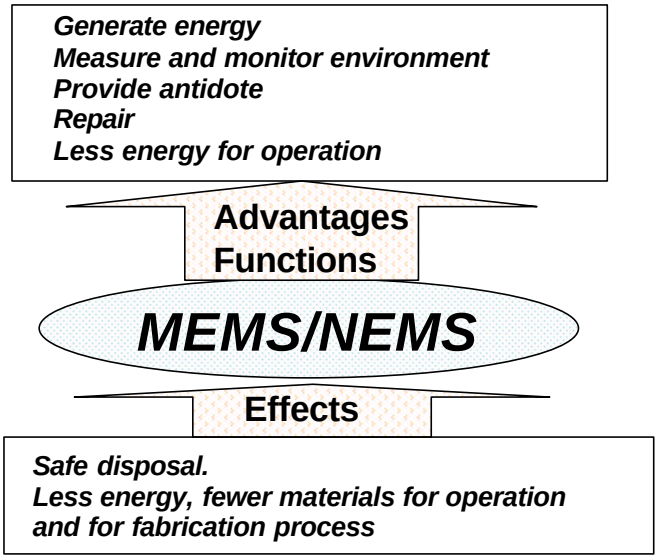


*Fig. 1: Effects and advantages/functions of MEMS/NEMS.*

In the context of environmental issues, I would like to classify the issues of MEMS/NEMS into two categories, effects and advantages/functions as shown in Fig.1. The effects come from three processes: fabrication, operation, and disposal. Up to now semiconductor micro-fabrication processes are mainly used to make MEMS/NEMS systems. The semiconductor processes are very useful for extremely mass production devices. On the other hand, since there is not usually a large market for these systems and making them is a complicated process that differs with each product, MEMS/NEMS products are expensive and moreover each product has its own manufacturing process. Thus, the MEMS/NEMS process needs to be flexible enough to allow a small amount to be produced and for a variety of products to be produced with less energy in addition to being cost effective.

Clearly, the operating MEMS/NEMS does not need much energy. However, there are a great number of these systems and each needs electrical energy. Sometimes primary batteries are used although the batteries are disposable and can cause waste or even toxins. Therefore, the way that they are operated is relevant to environmental issues. Another concern is the materials used to produce these systems; they should be both safe and able to be operated with a low level of electricity.

This article shows the advantages and requirements of MEMS/NEMS in terms of solving environmental problems. Using these systems could lead to many environmental problems being solved efficiently and at a low cost.

## 2. USE OF MEMS/NEMS TO MONITOR AND SOLVE ENVIRONMENTAL PROBLEMS

As shown in Fig. 2, environmental problems are divided into four categories: global, regional, and neighborhood ones, as well as those related to the interior of buildings. The first includes global warming, ozone layer destruction in the stratosphere, loss of tropical forests, acid rain, desertification, and cross-border movement of waste. The second includes the pollution of air, soil, and water, PCB pollution, pollution of underground water sources, the heat island effect, smog (including that caused by photochemical), loss of wildlife. The third includes the right of sunshine, noise, unpleasant odors, vibration, exhaust gas, wind gusts caused by tall buildings. Those relating to the interior of buildings include dust, formaldehyde, asbestos, vibration, sick house syndrome, electromagnetic wave, air current.

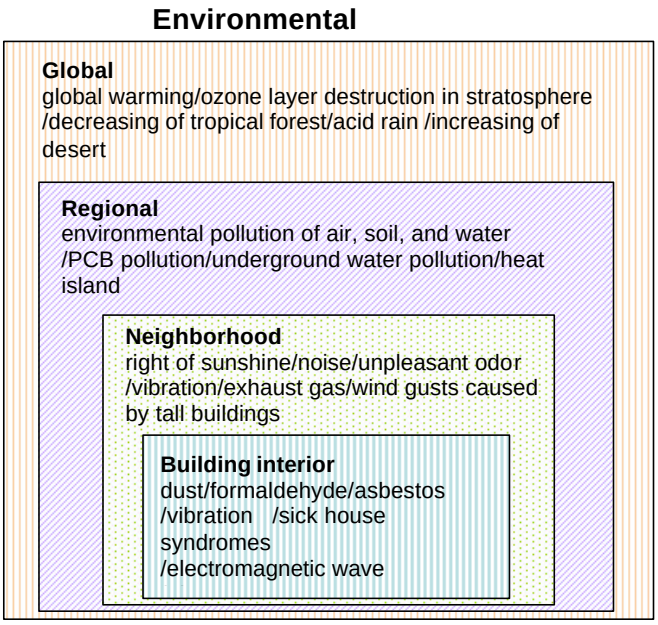


*Fig. 2: Four categories of environmental issues.*

A systematic approach for solving environmental issues [1] is shown in Fig. 3. To solve most of environmental issues, we first need to monitor their phenomena; this is a process that needs cost-effective and powerful measuring systems such as MEMS/NEMS. This measuring process involves three disciplines, scientific, technological, and social systems and the data collected is then made into an index of the features of a desirable environment.

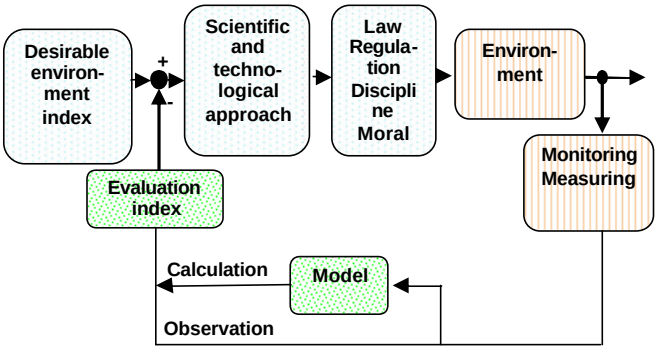


*Fig. 3: Systematic approach for environmental issues*

Another important issue is to investigate environmentally friendly information distribution technologies for building service systems that, through the use of multimedia capabilities, capture and distribute environmental information. Organizing environmental management systems, such as those that are used in ISO 14001 compliance, would be easier if quantitative measuring is possible. There is much

scope for MEMS/NEMS to be used to measure features of the environment cost-effectively and at a high level of accuracy. Since they do not disturb the environment MEMS/NEMS would be suitable for a wide variety of this kinds of environmental measuring. However, to date, MEMS/NEMS are seldom applied to quantify environmental issues.

## 3. EVALUATING THE ENVIRONMENTAL IMPACT OF MICRO/NANO SYSTEMS

The evaluation of environmental impact for MEMS/NEMS will seek ways to minimize environmental impacts of MEMS/NEMS fabrication facilities and operation, the effects of the MEMS/NEMS to the environment, and the effects of its disposal to the environment. One approach is to develop guidelines that take environmental audits into consideration. This might entail examining the equipment and operating methods from the standpoint of environmental risk management to see if there was any possibility of soil contamination, adverse effects from electromagnetic waves, and so on. Meanwhile, basic guidelines are also being developed that will enable a much more proactive environmental management approach; MEMS/NEMS equipment, systems, and services will be subjected to life-cycle assessment and the total cost calculated on that basis.

Semiconductor industries such as SEMANTECH in United States and SEAJ in Japan are working hard to decreasing the amount of power consumed in the semiconductor manufacturing process, and MEMS/NEMS industries have been requested to make the same level of effort.

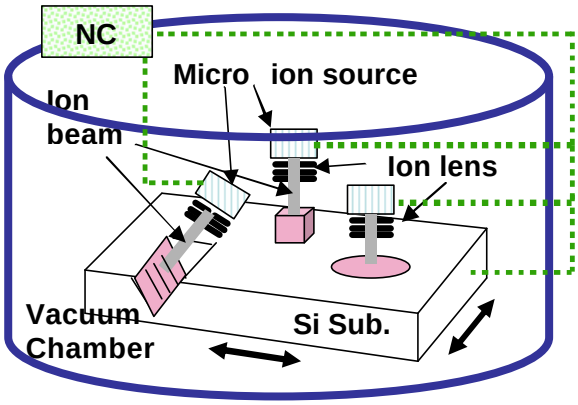


*Fig.4: An example of programmable sequence process by using micro-machined micro ion source units to reduce power consumption of manufacturing*

Semiconductor industries have very huge market and production is on a mass scale. Furthermore, its process and products are almost standardized. On the other hand, since MEMS usually do not have a large market and its fabrication process is complicated and different for each product, MEMS products are often expensive. Therefore, the MEMS process needs to be flexible and vary with small amounts and variety of products. Some researches for cost-reducing and flexible process have been published such as roll-to-roll process [2], applications of inkjet printer, imprint technology and so on. We propose the use of a flexible and concurrent MEMS manufacturing system [3] that uses micro-machined micro ion sources as shown in Fig. 4. The micro-machined micro ion source makes concurrent and simultaneous process easier in a chamber. The micro ion source unit generates ion beam currents of several μA with supplied electrical power of about 1 W. It will reduce the cost, power consumption, and space hitherto needed to produce MEMS products.

## 4. POWER MEMS/NEMS

Power generation systems are one of the most pressing subjects for global environmental issues such as global warming, acid rain, ozone layer destruction, harmful waste, etc. Especially, the recent rapid evolution of consumer electronics and Information Communication Technology (ICT) requires the use of distributed micro power supply systems. If we apply ordinary Grid or batteries for these electronics, we need wiring or changing batteries, that causes increasing energy waste and cost.

Ordinary power generation systems such as thermal power generation using fossil fuel, hydraulic power generation, and atomic power generation cause some environmental problems. For instance, burning fossil fuel generates $CO_2$, one of the main causes of the greenhouse effect. Although atomic power does not generate greenhouse gases, it seems difficult to reduce the cost of using it because of the high cost involved in keeping it harmless. It has been increasingly hard to find a new site for hydraulic power generation. These power generation systems are fixed centralization systems that cause electrical transmission power to be lost at cables that run between power plants and homes.

Renewable sources, such as solar power, wind power, geothermal power, biomass power, thermal energy conversion, fuel cell, and so on are expected to power generation systems that have either little or no harmful effects. However, these are seldom used on a commercial basis because of their high cost. Furthermore, they are not suitable for recent telecommunication systems and consumer electronics in which batteries are used as the power supply.

Recent consumer electronics and ICT power supply needs to be safe, highly reliable, and harmless to the environment, as well as compact and durable. Rechargeable lithium ion batteries mainly have been used for many kinds of applications, for instance, mobile phones, digital cameras, PCs, and other PDAs. However, the state of the art in the field of sensor network and medical examination and operation requires micro-scale maintenance-free power supply systems. One of the main targets of sensor networks is environmental sensing to measure phenomena such as $CO_2$ gas concentration, ozone layer density, acid rain, air pollution, soil pollution, water pollution, PCB, photochemical smog, temperature, and wind. The MEMS/NEMS power supply systems are now essential for micro-sensing systems of a ubiquitous network, micro-medical examination and operation systems in the human body, mobile phones, and so on.

The above is one of the reasons that The Japan Society of Mechanical Engineers has established Micro Energy Research Group under the professional Committee of Micro/Nano Engineering [4]. Also, Nano Energy Systems Research group [5] of Tohoku University, of which I am Research Director, has been working on many approaches to make MEMS/NEMS energy systems, such as vibration generators, micro fuel cells, bio-fuel cells, thermoelectric generators, and micro-reactors. Such systems would meet the demands for an ultra-distributed micro/nano scale maintenance-free power supply. Some of the work of this group will be shown in this symposium. We have included in our approach a power generation system that effectively changes low-density energies into electric energy by applying micromachining technology and many kinds of functional material. Sensor networks have also been studied as an application of MEMS/NEMS energy systems. In addition, we will also cover and develop the materials, the fabrication process, the disposal of wastes, and the operation load of MEMS/NEMS energy systems in terms of environmental compatibility.

## 5. CONCLUSION

MEMS/NEMS is a key technology that can be used to solve many kinds of environmental problems. Monitoring the environment and sharing information are the first steps in understanding and controlling the environment. Power MEMS/NEMS is also expected and essential to new business and new markets based on environmental compatibility. We have to consider both how to manufacture these products at a low level of power consumption and how the waste of MEMS NEMS products can be safely disposed of.

## ACKNOWLEDGEMENTS

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