Review on Sensor Materials without Lead

Dr. Su. J. Zhang
New Production Development, Mobrey Ltd. UK

Due to the requirement of RoHS, here is a brief review on sensing materials without lead.

Emerson Process Management companies use Lead Zirconate Titanate (PZT) as the sensing element in level, density, viscosity and flow instrumentation in order to convert the electric energy into mechanical energy or *vice versa*.

Our instrumentations monitor the level, density, viscosity and flow changes in real time in hazardous industrial environment. Thus, it leads to high performance requirements on our sensing elements in electro-to-mechanic conversion efficiency, working temperature, frequency range, corrosion tolerance as well as element shapes and manufacture capability.

Apart from the PZT family, a few of materials without lead available in market place, are able to convert the electric energy into mechanical energy or vice versa. However, they have different shortcomings in the applications of our instrumentations. Some of these materials are commented as below.

1. Barium titanate

The barium titanate was the first man-made piezoelectric ceramic material used in microphone and transducer. However, it was largely replaced by PZT because of its low Curie's temperature (~115 ^{o}C) and poor temperature performance. In terms of electro-mechanical performances, its transmitting (electro-mechanic) capability is about a third of PZT's; its receiving (mechanical-electro) capability is about half of PZT's.

2. Magnet based on rare earth materials

Electromagnetic material is another way to convert the electric energy to the mechanic energy or *vice versa*. One of typical giant magnetostrictive materials is Terfenol-D. It has super electro-mechanic performances in the frequency range below 2kHz. With the increase of working frequency, the heat is induced by the material loss. Thus, this material only shows its advantages in the audio frequency range.

3. Copolymer

In 1969, the strong piezoelectric properties of PVF_2 were firstly observed by Kawai *et al.* It leads to the development of piezoelectric plastic films. Then, copolymer P(VDF-TrFE) occurred with a further improvement on its electro-mechanical conversion efficiency.

Copolymer has a super performance in its receiving capability (mechanic-to-electric conversion) and is suitable for a light weight receiving sensor. Compared to PZT, it is not suitable for the transmitting and has a lower working temperature (<100 ^{o}C).

4. Electromechanical film

Electromechanical film is widely used in the transducer working in air. It is a thin film with thickness of about 100μm with coated electrodes on both sides of film. A high bias voltage has to be applied to the film in order to make it work. Furthermore, its working temperature is less than 60 ^{o}C. Thus it is most suitable for non-industrial applications.

5. Bismuth Titanate

Bismuth titanate belongs to the group of sillenite structure-based ceramics ($Bi_{12}MO_{2}0$ where M=Si, Ge, Ti). It has a very high Curie temperature so that it is able to operate at temperature of up to 550°C. The materials exhibit low dielectric constant, low dielectric loss and properties stable up to very high temperatures. But, compared to PZT, it has shown poor piezoelectric effects in transmitting. Bismuth titanate ceramics are mainly used as a receiver in high temperature applications such as pressure sensors and accelerometers.

Table 1 lists a comparison of their typical properties. Properties of PZT5A is also included for reference.

Sensor material	Density (kg/m^3)	d_{33} (transmitting, charge coefficient) 10^{-12}C/N or mV^{-1}	g_{33} (receiving, voltage coefficient) 10^{-3}Vm/N	k_{33} (Coupling factor)	Maximum working temperatur e (^{o}C)	Optimum working frequency (kHz)
PZT (5A)	7800	374	25	0.71	250	10~10000
Barium titanate	5600	120	12	0.65	100	10~10000
Terfenol-D	9210	1700 (10^{-12}mA^{-1})	---	0.72	300	0.01~20
Copolymer	1800	30	250	0.2	100	100~10000
EMFi	--	200	--	--	50	0.02~20
Bismuth titanate	6550	18	17	0.09	550	10~10000

Table 1. The typical properties of different sensor materials.

Last but not least, when we choose a sensing material, apart from the considerations of its conversion efficiency, working temperature and frequency range, we must also consider the feasibility of it's integration into a sensor housing in order to resist a hazardous industrial environment. The sensor housing and the internal structure of sensor will also have a large impart on the efficiency of sensor performance.

Therefore, with our best knowledge so far, no other material without lead is capable of replacing PZT as the sensor element for our instrumentation in terms of overall performances.

Reported by : Dr. Su. J. Zhang (Senior Physicist)
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