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Lead-Free Piezoelectric Vibration Sensors for Condition Monitoring of Nuclear Facilities

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1. Introduction

Because there have been global considerations, laws and regulations, spreading from the European Union to many other parts of the world, strongly demanding the elimination of lead-based materials from all consumer items [1,2], there is a pressing need to develop lead-free piezoelectric materials as a viable alternative to traditional lead-containing $Pb(Zr,Ti)O_3$ (PZT) piezoelectric ceramics. In addition to developing alternative materials, the successful application of lead-free materials requires steps, including, in particular, the design, fabrication and performance validation of a piezoelectric device built using a lead-free material system.

In efforts to develop nontoxic replacements for PZT, in this work piezoelectric-type vibration sensors, such as accelerometer and acoustic emission (AE) sensors, [3] were designed, fabricated and characterized by using a lead-free modified $(K,Na)NbO_3$ (KNN) piezoceramics.

2. Methods

The polycrystalline KNN-based ceramics to be integrated into a sensor prototype were prepared using the conventional solid-state powder method. The details of preparation conditions are described [4,5] The KNN was modified by a mixture of two Bi-based perovskites, $Bi(Na,K,Li)ZrO_3$ (BNKLZ) and $BiScO_3$ (BS). The material composition used in this work was 0.96KNN-0.03BNKLZ-0.01BS. The sintered ceramics had densities of 4.25–4.32 g/cm^3 (greater than 95% of the theoretical density), determined based on the Archimedes method. The types of the ceramic samples to be integrated into a sensor prototype were disk and ring.

The prototypes of accelerometer and AE sensor were fabricated according to the proposed designs. [6] The internal components such as head, tail and base were manufactured and assembled. Typical designs of accelerometer and AE sensor are shown in Fig. 1 (a) and (b), respectively. Finally, the sensitivity and frequency response characteristics of the fabricated accelerometer and AE sensor prototypes were evaluated using the experimental setup for the vibration test.

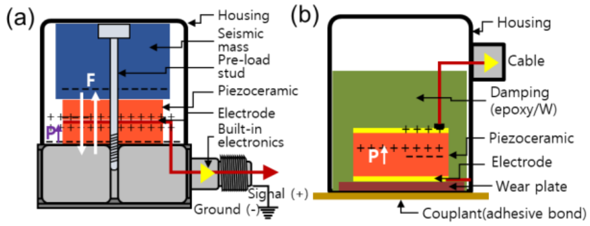

Fig. 1. Basic designs of a vibration sensor prototype : (a) accelerometer and (b) AE sensor

3. Results

Fig. 2 (a)-(d) show the material properties of lead-free KNN-BNKLZ-BS ceramic. The average grain size was 114 μm. The ceramic had coexisting phases of rhombohedral (R) and tetragonal (T), whose compositions were 16 % and 84 %, leading to T-rich R-T structure. The measured piezoelectric charge constant d_{33} and Curie temperature T_C were 340 pC/N and 330 ^oC, respectively.

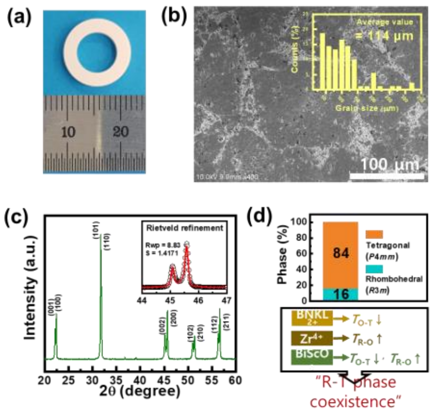

Fig. 2. Material characteristics of lead-free KNN-BNKLZ-BS ceramic: (a) a photo of sintered ceramic ring (O.D.: 12.6mm, I.D.: 7.5mm, t: 2.6mm). (b) SEM image showing a typical microstructure (inset is grain size distribution). (c) Normal θ–2θ XRD pattern (inset shows Rietveld refinement). (d) Quantitative phase composition and resultant phase structure.

Fig. 3 (b) and (c) show the properties of accelerometer sensor built using a lead-free KNN-

BNKLZ-BS ceramic. The measured sensitivity and mouinted resonant frequency were 101 mV/g and 36 kHz, which were almost comparable to or higher than those observed in PZT-based sensor (Fig. 3 (b) and (c)).

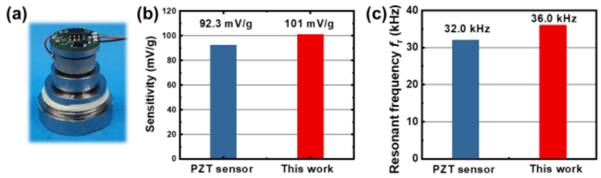

Fig. 3. (a) a photo of lead-free accelerometer prototype. (b) sensitivity. (c) mounted resonant frequency.

Fig. 4 (c) shows the properties of wideband width AE sensor built using a lead-free KNN-BNKLZ-BS ceramic. The measured frequency response range is between 100 and 1000 kHz, which is comparable to that observed in PZT-based sensor (Fig. 4 (b)).

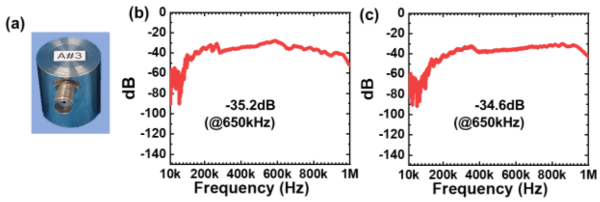

Fig. 4. (a) a photo of lead-free AE sensor prototype. (b) PZT-based AE sensor. (c) lead-free AE sensor (this work).

4. Conclusions

By using a lead-free modified KNN piezoceramics, in this work, piezoelectric-type vibration sensors, such as accelerometer and acoustic emission (AE) sensors, were designed, fabricated and characterized. Well-prepared lead-free KNN piezoelectric ceramics guaranteed the good sensing properties when applied to accelerometer and AE sensors. The proposed KNN-based sensors show potential to successfully replace traditional PZT-based piezoelectric sensors.

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