JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **8** No 4(2), 04089(3pp) (2016)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **8** № 4(2), 04089(3cc) (2016)

Short Communication

Digital Piezomaterial Based on Piezoceramic-Polymer Composite for Ultrasonic Transducers

D.I. Makarev, A.N. Rybyanets

Research Institute of Physics, Southern Federal University, 344090 Rostov-on-Don, Russia

(Received 12 August 2016; published online 23 December 2016)

Laboratory samples of digital piezomaterial with high mechanical Q-factor based on the mixed piezoceramic-polymer composite adapted for the piezoelectric elements manufacturing (by the additive technology of powder layer binding) were obtained. The material Q-factor dependence of the sound velocity ratio of the piezoceramic and polymer was determined. It is shown that ultrasonic transducers for a number of technical applications can be made on a basis of this piezomaterial.

Keywords: Digital piezomaterial, Composite, Additive technology, Ultrasound.

DOI: 10.21272/jnep.8(4(2)).04089 PACS numbers: 62.23.Pq; 43.38. + n

1. INTRODUCTION

Additive technology of powder layer binding (binding powder by adhesives) is one of the most promising technology for the manufacturing of mixed "ceramic-polymer" composite materials (including composite piezomaterials [1]), and ceramics [2] on the 3D printer. We have proposed [3] the technology of digital piezomaterial manufacturing based on "piezoceramic-polymer" mixed composite, which can be used as a consumable item for powder layer binding technology.

We had to slightly modify this technology to remove the negative effects associated with huge difference in the dielectric constants of piezoelectric ceramics and polymer. We had to increase the size of piezoceramic particles to several millimeters in order to create an element consisting of a single layer of piezoelectric ceramic particles, thereby preventing the emergence of continuous polymer layers between the electrodes of the composite samples. As a result, the particles ceased to be powder and the technology become single-layered. However, a single layer of coarse particles in the polymer matrix can be considered as a limiting case of the technology. In the future, we plan to return to the production of composites with several layers of piezoceramic particles with size of 10-100 μm.

The resulting material has two main structural features compared to other similar composites

Firstly, the initial particle size of the piezoceramic component exceeds the final thickness of the piezoelectric elements made of this composite. On the one hand, it prevents the emergence of polymer interlayers between the electrode and the piezoceramics; on the other hand, it creates the necessity of machining the elements while manufacturing. Secondly, in this composite piezoceramic particles are in a single layer. The values of its piezoelectric coefficients measured with quasi-static method equal to 0,8-0,95 part of the piezomoduli values of the piezoceramics. The single-layer composite have a low mechanical Q-factor, which provides a number of advantages, but limits the application area.

2. CONCEPT HEADINGS

The low mechanical Q-factor of the piezoelectric elements, along with their good acoustic matching with media with low acoustic impedance, such as water, oil, plastics and oil products, allows to make broadband ultrasonic transducers for different applications such as defect inspection, medicine, hydroacoustics, and others. However, there is also a need for transducers with an average width of bandwidth (20-40 %) on the level 6 dB, for example, burst mode ultrasonic transducers such as doppler medical sensors, transducers for ultrasonic flowmeters, sonar transducers, and others. There is also a need for the power pulse emitters acoustically agreed with these media, in particular for a power ultrasonic emitter operating with oil and oil products, capable producing sonication of wells in pulse mode. For these applications,we need piezoelements with a Q-factor of at least 2 times exceeding the Q-factor of ultrasonic transducers made on their basis.

It provides the possibility of damper, protector or matching layer applying, that generally extends the transducer bandwidth and reduce its Q-factor. Therefore, there is a need for a piezomaterials manufactured by the same technology with Q-factor managed without significant change in manufacturing technology. We can manage the Q-factor of the single-layered composite replacing a bonding polymer or piezomaterial by changing the concentration of piezoceramic particles in the composite, as well as varying the porosity of the piezoceramic particles. The latter method seems to be the most promising because it allows smoothly adjust various properties of the composite while maintaining the high values of its pezoimoduli.

The Q-factor of the composite is deteriorating because of acoustic mismatch of the two main subsystems constituting the composite: piezoelectric ceramics and polymer. And the difference in their sound velocities plays a more significant role than the difference in densities, since mismatching of the sound velocities leads to mismatching of the mechanical resonances of these subsystems, and this affects the overall mechanical Q-factor of the composite. Thus, the purpose of this work was to study the effect of the ratio of the sound velocities of the two main components of the single-layer composite system "piezoceramic-polymer" on its Q-factor in order to obtain the number of digital composite piezomaterials with controlled mechanical Q-factor based on this composite, which could be manufactured by a modified additive powders bonding technology in order to use such piezoelectric materials as working elements in pulsed and radiopulsed ultrasonic transducers and power ultrasonic pulsed emitters.

The mixture of a 99 wt % porous piezoceramics PKR-1 in the form of particles ranging in size from 1 to 3 mm and 1 wt % acrylic polymer was taken as the initial "powder". A mixture of benzoyl peroxide, an acrylic monomer and *N*, *N*- dimethyl-*p*-toluidine were taken as the liquid curing agent [3].

3. RESULT

As a result we created a mixed composite material with porous piezoelectric ceramics of 80 vol %. The elements in the form of discs with a diameter of 20 mm and a thickness of 2.5 mm were manufactured from this material.

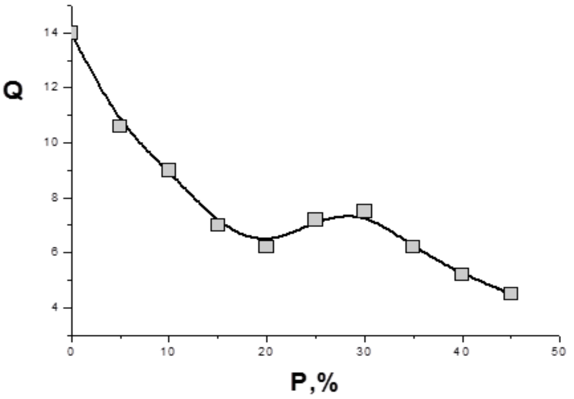

Fig. 1 – Dependence of the mechanical Q-factor of the single-layered piezoceramic-polymer composite on the porosity of the PCR-1 at the polymer sound velocity of 2700 m/s

The sound velocity in a porous piezoceramic material depends significantly on its porosity, particularly The sound velocity in porous piezoceramics PKR-1 calculated by antiresonant frequency of piezoelectric elements in the form of thin disks continuously nonlinearly varies from 1200 m/s at a porosity of 40 % to 4000 m/s at porosity close to zero [4]. The sound velocity in constituting the composite acrylic polymer was measured on disks of the polymer with a diameter of 20 mm and a thickness of 2, 3, 5 mm by pulse ultrasonic method at a frequency of 5 MHz, its mean value was 2700 m/s, which approximately corresponds to the middle of the sound velocity changes range in the porous piezoceramics PKR-1, depending on the porosity. Therefore, it is convenient to trace the dependence of the material Q-factor from the ratio of sound velocities in the porous piezoelectric ceramics and polymer modifying the porosity of the piezoceramics and unchanging composition of the polymer. Standard methods for measuring the Q-factor were not applicable for the elements with such a low Q-factor, so the Q-factor of the composite was considered as the ratio of the real and imaginary parts of the elastic stiffness module C33D. The measurements were performed using an impedance analyzer Hioki 3532. The calculations were performed using PRAP program. The dependence of the Q-factor of the single layered mixed composite consisting of porous piezoceramics PKR-1 particles in the polymer matrix, from the piezoelectric ceramics porosity shown on Fig. 1.

4. DISCUSSION

The figure shows that the maximum Q-factor of the composite corresponds to zero porosity, which is understandable, since the maximum Q-factor of the initial piezoelectric ceramics are also corresponds to zero porosity, and the Q-factor of the initial piezoelectric ceramics decreases monotonically with increasing porosity, and 60 % porosity Q-factor equals to 0.2 part of zero porosity Q-factor [5]. Furthermore this graph has a local maximum at a 30 % porosity.

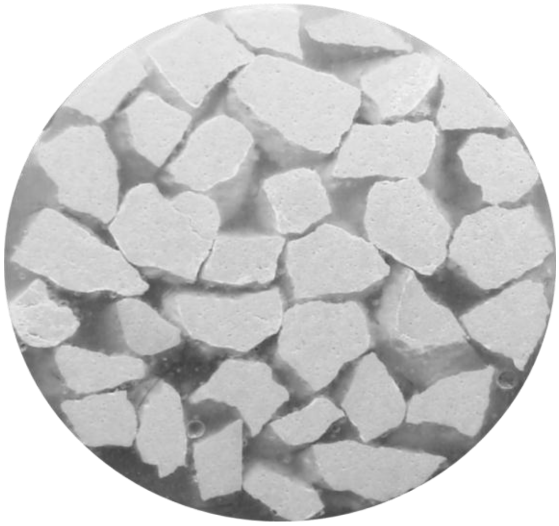

Fig. 2 – Photograph of the single-layered piezoceramic-polymer composite. The diameter of the disc is 20 mm

Porous piezoceramics PCR-1 with a porosity of 30 % have the sound velocity equal to 2800 m/s, which is almost coincide with the sound velocity in the polymer included in the composite. Thus, it can be concluded that polymeric and piezoceramic subsystems of the composite in this case have mechanical resonances at the same frequency and the frequency coincidence leads to an increase of mechanical Q-factor, respectively, speed coincidence causes the existence of a local maximum on the graph. Q-factor reaches the value of 7 at the local maximum, indicating the suitability of this material for the manufacture of ultrasonic transducers having an average transmission bandwidth. The single-layer piezocompozite without electrodes is shown in Fig. 2. Light particles in the photograph are the particles of the porous piezoelectric ceramics PCR-1 with a porosity of 30%, a dark translucent material between the particles is the binder polymer.

5. CONCLUSION

Thus, it can be concluded that the ratio of the sound velocities in piezoelectric ceramics and polymer in the single-layer composite system "piezoceramic-polymer" affects the Q-factor of these composites. The local maximum Q-factor of the composite is observed in the coincidence these speeds, and the Q-factor reaches values that allow to create ultrasonic transducers for various applications including flaw detection, medicine, hydroacoustics, etc on the basis of the composite.

Also it allows to create single-layer composites with a wide range of properties varying the consistency of the sound velocity in the piezoceramics and polymer by changing porosity of the piezoelectric ceramic particles.

6. ACKNOWLEDGEMENTS

The study was performed by a grant from the Russian Science Foundation, project № 15-12-00023.

REFERENCES

1. V.V. Eremkin, A.E. Panich, V.G. Smotrakov, *Tech. Phys. Lett.* **31**, 669 (2005).
2. V.I. Aleshin, E.S. Tsikhotsky, V.K. Yatsenko, *Tech. Phys.* **49**, 61 (2004)
3. D.I Makarev, A.N. Rybyanets. G.M. Mayak, *Tech. Phys. Lett.* **41**. № 4. 317 (2015).
4. A.N Rybianets *Ferroelectrics* **360**. № 1, 84 (2007)
5. A.N Rybyanets, O.N. Razumovskaja, L.A. Reznitchenko, V.D. Komarov, A.V. Turik, *Integr. Ferroelectr.* **63**, 197 (2004).