PRIMENA DEBELOSLOJNE TEHNOLOGIJE U PRIKUPLJANJU ENERGIJE IZ OKOLNE SREDINE

THICK-FILM TECHNOLOGY FOR ENERGY HARVESTING

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Prikupljanje energije iz okolne sredine je jedna od novih potencijalnih primena konvencionalne debeloslojne tehnologije. Da bi se smanjila upotreba baterija razvijaju se novi, čisti i obnovljivi izvori energije koji prikupljaju energiju iz okolne sredine. Jedno od potencijalnih rešenja se zasniva na korišćenju različitih izvora vibracija pri čemu se koriste piezoelektrični pretvarači koji mogu biti formirani tehnologijom debelog filma. Debeloslojni piezoelektrični materijali se mogu upotrebiti za formiranje samostojećih debeloslojnih struktura sličnih gredicama koje pod dejstvom naprezanja generišu električni odziv. Za razliku od struktura formiranih primenom mikromašinstva ili tankoslojne tehnologije, debeloslojni piezoelektrični mikrogeneratori sadrže samostojeće strukture debljina većih od 50 μm i površina iz opsega od nekoliko mm^2 do nekoliko cm^2 . Postoji više potencijalnih problema koje treba razmotriti kada su u pitanju debeloslojne samostojeće strukture. Oni obuhvataju uslove formiranja i procesiranja samostojećih struktura kao i njihove performanse u uslovima naprezanja. U radu će biti razmotrena ova pitanja kao i mogućnost pouzdanog formiranja i eksploatacije debeloslojnih piezoelektričnih mikrogeneratora.

Ključne reči: prikupljanje energije iz okolne sredine; debeloslojna tehnologija; PZT; samostojeće debeloslojne strukture

Energy harvesting is one of the latest possible applications of thick-film technology. In order to replace traditional batteries, energy harvesters are being developed that provide clean and renewable energy sources. Vibration-based harvesting is one of the possible solutions where vibration to electricity conversion mechanism can be implemented using piezoelectric transduction compatible with thick-film technology. Thick-film piezoelectric materials could be used to form free-standing structures similar to traditional cantilever structures that when stressed generate electrical charges. Unlike structures formed using micromachining and thin-film technology, thick-film energy harvesters may provide free-standing structures with thicknesses greater than 50 μm covering area from several mm^2 to several cm^2 . There are several challenges in realization of such thick-film free-standing structures that have to be addressed. They involve both processing conditions and operation in bending mode. This paper aims to address these challenges and explore feasibility of reliable formation and exploitation of thick-film piezoelectric micro generators.

Key words: Energy harvesting; thick-film technology; PZT; free-standing thick-film structures

1 Introduction

Conventional thick-film technology has been used for several decades in production of various forms of electronic circuitry for both commercial and custom applications. At first it was used for realization of wide variety of resistor networks and, later on, mostly for realization of custom hybrid integrated circuits. Over the time interest in thick-film technology seized but new applications emerged and over the past two decades researchers paid special attention to thick-film sensing capabilities [1-2] and new potential applications in micro-electro-mechanical systems (MEMS) [3-4] and lately in energy harvesting [5-6].

When sensing capabilities are in question one of the greatest assets of thick-film technology is the ability to produce sensing, actuating and signal processing circuitry on a single ceramic substrate. It was found that even conventional thick-film resistors are strain sensitive [7]. This highly undesirable property when conventional applications are in question was used in strain sensing applications and

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development of materials with high piezoelectric activity enabled realization of various thick-film strain gauge elements.

When vibration-to-electricity conversion was brought into spotlight with advancements in pervasive systems that require renewable and clean sources of energy, thin and thick-film technologies compatible with silicon based integrated circuits seemed like good options for realization of micro scale free-standing structures that could be used as ambient energy harvesters. However, there are several issues that have to be addressed when production of reliable free-standing thick-film structures are in question. This paper aims to address these limitations of thick-film technology based piezoelectric micro generators in terms of size, processing conditions and performances in comparison with thin-film technology.

2 Free-standing thick-film structures

Thick-film technology has been used for decades in production of various forms of electronic circuitry. Typically, thick-film structures are formed using standard screen printing process, followed by the wet layer leveling at the room temperature, drying in an infrared belt furnace for 15 min at 150 °C and firing in a conveyor furnace in 30-60 min cycle with 10 min at peak temperature of 850 °C. During the drying process all organic solvents evaporate from the wet layers. During firing, thick-film composite materials with borosilicate glass and conducting phase as base ingredients solidify and adhere to the ceramic substrate. However, conventional fabrication techniques do not support realization of free-standing thick-film structures. Such structures are usually being formed using silicon micromachining or thin-film technology. Depending on application they differ in sizes but are generally small and can be of submicron dimensions.

In order to support formation of free-standing structures thick-film technology had to adopt fabrication techniques that involve use of sacrificial layers and high piezoelectric activity materials [8]. Thick-film micro generators are usually realized in the cantilever form. Bending mode of the cantilever is being used for energy harvesting from low acceleration levels and frequencies. Production process of the thick-film cantilever structure (Fig.1) starts with the screen printing of the sacrificial layer on top of the alumina ceramic substrate. On top of the sacrificial layer electrode is being formed by conducting thick-film composition screen printing, followed by screen printing of the high piezoelectric activity thick-film material, usually lead zirconate titanate (PZT) based composition. On top of the PZT another layer of conducting material is printed thus forming the second electrode layer. After firing in a conveyor furnace in an adequate atmosphere sacrificial layer is burnt out without residues releasing the free standing thick-film cantilever structure. To complete the production process polarization of the piezoelectric layer should be performed.

Fig. 1. Formation of the free standing thick-film cantilever structure

Formed structure at one end physically adheres to the ceramic substrate that serves as a supporting base and freely moves at the other end. The greatest asset of such thick-film free-standing struc-

tures is the possibility of printing other sensing thick-film materials upon the structure and simple integration with other electronic circuitry. In terms of reliability, the key factors to successful formation of thick-film free standing structures are: strict screen printing and firing process control, selection of optimum thick-film compositions, achieving uniform layer thickness, formation of crack-free fired films of high mechanical density and achieving adequate piezoelectric performances.

When compared to thin-film and micromachining techniques, thick-film technology based free-standing structures have two opposing assets: cost and size. Production costs are significantly reduced since complex and expensive processes required by thin-film and micromachining technology are avoided. However, thick-film technology is suitable for production of larger structures covering areas ranging from $n \times \text{mm}^2$ to $n \times \text{cm}^2$ and thicknesses $>50 \mu\text{m}$. Thicker structures are capable of generating more of the electrical energy but are less elastic and for ambient energy harvesting applications cantilever thickness is of the greatest importance. Apart from the benefits of a cost-effective, relatively simple and reproducible production process there are several other issues that should be taken into account. Alumina substrate, serving as a supporting platform, needs to withstand operation in a bending mode, screen-printing process involves high contact forces and high peak firing temperatures, the resonant frequency of the free-standing structure has to match the ambient vibration sources. All of these issues have to be taken into account in order to produce efficient and reliable thick-film micro generator.

3 Conclusion

Over the years several thick-film micro generator prototypes have been designed and realized [4, 5] because of their cost effectiveness and ease of fabrication. However, their implementation is still being investigated and researchers are facing various challenges. Ambient vibration sources have changing vibration frequencies and the power outputs of vibration-based thick-film micro generators are significantly sensitive to vibration frequencies. Such erratic nature of vibration sources, along with lack of elasticity of the substrate that limits cantilever performances, optimum thickness of the cantilever structure necessary to harvest energy, production process parameters that affect reliability of the free-standing structure are some of the key issues that have to be taken into account when the choice of the adequate technology for micro generator fabrication is being chosen. Further investigations should be performed that include novel materials selection, optimization of processing and firing parameters, alternative designs in order to make thick-film technology competitive when ambient energy harvesting is in question.

4 References

- [1] **White N.M. and Turner J.D.**, Thick-film sensors: past, present and future, *Measurement Science and Technology*, Vol. 8, No. 1, pp. 1-20, 1997.
- [2] **Aleksić O., Nikolić M.V., Luković M., Stanimirović Z., Stanimirović I., Sibinoski L.**, The Response of a Heat Loss Flowmeter in a Water Pipe Under Changing Flow Conditions, *IEEE Sensors Journal*, Vol. 16, No. 9, pp. 2935 – 2941, May 1, 2016.
- [3] **Belavič D., Hrovat M., Holc J., Zarnik M., Kosec M., Pavlin M.**, The application of thick-film technology in C-MEMS, *Journal of Electroceramics*, 19(4), pp. 363-368, 2007.
- [4] **Dorey R.A., Whatmore R.W.**, Electroceramic Thick Film Fabrication for MEMS, *Journal of Electroceramics*, Vol.12, Issue 1–2, pp. 19–32, 2004.
- [5] **White N.M., Glynn-Jones P., and Beeby S.P.**, A novel thick-film piezoelectric micro-generator, *Smart Mater. Struct.*, vol. 10, pp. 850-852, 2001.
- [6] **Kok S.L., White N.M. and Harris N.R.**, A Free-Standing, Thick-Film Piezoelectric EnergyHarvester, *Proceedings, SENSORS 2008 Conf.*, IEEE, Lecce, Italy, pp. 589 – 592, 2008.
- [7] **Stanimirović I., Stanimirović Z.**, Modelling and simulation of standard TFRs as strain sensing elements, *Proceedings, Small Systems Simulation Symposium*, Niš, Republic of Serbia, pp. 54-57, 2016.
- [8] **Stecher G.**, Free supporting structures in thick-film technology: A substrate integrated pressure sensor, *Proceedings, 6th European Microelectronics Conf.*, Bournemouth, UK, pp. 421-427, 1987.