European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Design and Fabrication of Piezoresistive Strain-Gauges for Harsh Environment Applications

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Abstract

Maximum operating temperature is usually one of the limiting factors for using of conventional sensors and other electronic devices. High-temperature sensors and electronics are required in some special applications e.g. measurement of deformations, stresses and pressures inside power generators. The design methodology of the some piezoresistive sensors utilizing FEM simulations is presented. Piezoresistive sensors based on thin-film metal sputtered layers, silicon-on-insulator (SOI) and nanocrystalline diamond layers (NCD) were successfully designed, fabricated and measured. The fabricated sensors are able to operate at temperatures up to 250 °C. Extensive study of sensor parameters e.g. deformation sensitivity, edge and contact resistances, temperature dependences gauge factor, bridge output voltage was performed. The measured values and investigated findings can be used for calibration of simulation software and in prospective design of more complex sensor structures.

Piezoresistivity is one of the widely utilized physical phenomena in different kinds of sensor devices.]. The basic function of the strain gauge is based on transforming the strain in certain direction as to change its electric resistance. It allows measuring plenty of non-electrical quantities such as deformation, bending, force, acceleration etc.

The aim of this paper is to introduce specific design, fabrication and characterization techniques of high-temperature deformation sensors. Each used technology somehow improves the performance of sensors fabricated within the previous one.

The first piezoresistive sensors were based on the thin-film sputtered metallic layers. The aim was to find a material with reasonable deformation sensitivity. The materials used were e.g. Nichrome, Chromium Silicide and Tantalum Nitride. For application at elevated temperatures, a suitable contact system was developed and its optimization and stabilization of parameters at high temperatures was performed.

Next were the sensors based on SOI (Silicon-on-insulator). The SOI technology provides excellent compatibility with CMOS process and is suitable for operating temperatures up to 300 °C. Moreover, strain gauges based on crystalline silicon exhibits high deformation sensitivity.

Last were the sensors based on thin film nanocrystalline diamond layers. This technology is not as well established as the previous one, but unique mechanical and electrical properties of diamond promise applicability at very high temperatures. At present time, not only sensors of physical and electrical quantities are developed on diamond, but diamond layers are used in medicine and biomedical engineering as well.

The selection of the suitable fabrication technology was obeyed by requirement on higher operational temperatures of fabricated samples.

The extensive study of sensor parameters e.g. deformation sensitivity, edge and contact resistances, temperature dependences gauge factor, bridge output voltage was performed. A suitable contact system with stable parameters at elevated temperatures, methodology of measurement and special measurement setup was developed.

The deformation sensitivity of GF = 3.3 (-) and TCR = 30 ppm/K is presented for strain gauges with nichrome metal layers. The silicon (SOI) exhibits very good sensitivity (GF ~55) and linearity, in spite of relatively high doping level (resistivity 0.01 ÷ 0.02 Ω·cm).

NCD strain gauges exhibit higher gauge factor compared to strain gauges having sputtered metal layers. However, the gauge factor of NCD piezoresistors is still lower than that measured for SOI. The GF presented in this paper is 8.4 (-) at 25 °C for resistivity of $\rho \sim 0.015$ Ω.cm.

The measured values and investigated findings can be used for calibration of simulation software and in prospective design of more complex sensor structures. .

The proposed newly developed sensor structures are very attractive for reasonable parameters and performance at higher operating temperatures.

Key words

piezoresistivity, strain-gauges, FEM, high-temperature application