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Microwave sensor for mechanical stress measurement based on ferroelectric graphene nanosheet composites

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Abstract

It was shown that composite materials based on Pb(Zr1-xTix)O3 (PZT) ferroelectric particles, covered with graphene nanosheets, can be used for wireless detection of force applied to those composites. Ferroelectric materials with their enhanced piezoelectric and emission properties are used in this case as electron sources. During the mechanical loading of composites so called ferroelectric emission (FEE) appears in form of shot impulses of electrons. The short electron impulses generate the intensive microwave impulses that can be detected by means of antenna. This composite could be used as sensor for wireless measurement of machinery components response on applied stress in the locations where the connection with cables is restricted.

Keywords: Ferroelectrics, Microwave emission, graphene nanosheets, stress measurement, PZT

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1. Introduction

Usually the measurement of the deformation of machinery components and crack initiation processes inside these components requires bulky applications [1,2]. In most cases such applications involve expensive devices with large connecting wires like acoustic emission sensors [3–6]. Replacing these devices with small pieces of composites is a challenging task where the charge fluctuation on ferroelectric composite surfaces can be created by mechanical stressing (piezoelectric effect) and induce FEE. It is necessary to distinguish between two kinds of FEE - ‘‘weak’’ and ‘‘strong.’’ The characteristic future of ‘‘weak’’ FEE are emission bursts with characteristic current density between 10^{-12} and 10^{-7} A/cm^2 [7]. These electron emission bursts are responsible for microwave generation.

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The dominant mechanism of “weak” FEE is the field emission from crystal imperfections where a significant enhancement of electrical field takes place. Caused by low conductivity of ferroelectric materials the emission i.e. discharge, occurs only from small sites around the crystal imperfections. Consequently, a low current density is a characteristic future of “weak” FEE. However, due to short emission times of electrons an intensive microwave emission can be achieved [8].

The magnitude of the ‘‘strong’’ FEE is about 10 or 12 orders higher than the magnitude of ‘‘weak’’ FEE. Indeed, to excite the “strong” FEE a pattered metallic electrode has to be deposited on the polar ferroelectric surface [9]. The electrode of this configuration induces not only the normal component, but also a tangential component of the applied electric field, which causes the generation of flashover-plasma and expansion of conductive plasma along the ferroelectric surface. Consequently, compared with “weak” FEE, the rise time of accelerated electrons is short [10,11]. In this context a new device based on ferroelectric and graphene nanosheet composite that integrates both effects – a short rising time and high density current is very promising. On the one hand the charge is collected from the surfaces of ferroelectric particles coved with conducting graphene nanosheets (GNS) and “strong” FEE achieves. On the other hand due the high conductivity of graphene nanosheets the electron emission time is very short [12].

2. Materials and Methods

2.1. Materials

The composite contained two several materials. A piezoelectric body was formed from typical “PIC 181 PI Ceramic” PZT-material and polarized then at 5 kV. Then the body was milled to a powder with an average particle size between 80 and 120 µm. The powder was mixed with 0,01% wt. “CP-0082 iolitec” - graphene nanosheets with a width of 2 nm and SSA of 500 m²/g. This mixture was formed to a composite specimen by sealing into “Sylgard 184” elastomer and hardening for 30 minutes at 100 °C.

2.2. Experimental set-up

The stress initiation inside the specimen was simulated by mechanical loading tests with a 200g- metallic cylinder. The cylinder was fixed over the specimen in a distance of 50 mm by a bolt. After the remove of the bolt, the cylinder fell on the specimen and enhanced the microwave emission from the composite, see figure 1.

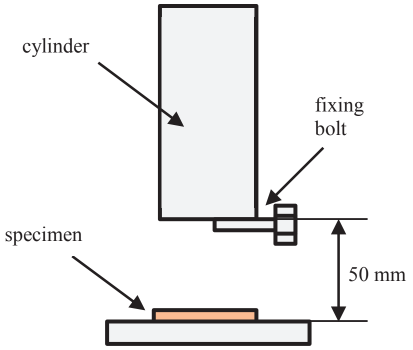

Figure 1. Experimental set-up.

2.3. Measurement set-up

The electromagnetic emission was measured in a frequency range from 8 to 12 GHz with an X-band horn antenna, see figure 2. The signal, received by horn antenna, was amplified by the use of a broadband microwave amplifier 83017A (Agilent Technologies). This amplifier has a gain of 25 dB that can be used over a 26.5 GHz bandwidth. The