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ABSTRACT

Among the objectives of sustainable development, improving energy efficiency and reducing the use of materials with limited resources are particularly important in the field of electronics. Harvesting unused energy in a given environment in order to make an electrical device autonomous, and therefore avoiding the use of a battery, is in line with these objectives. In addition, the rapid growth of the Internet of Things is raising questions about the environmental impact of connected objects such as "autonomous wireless communicating sensors". The reduced energy consumption of these devices means that ambient energy sources can be used to power them with energy harvesting modules instead of batteries. In particular, since the 2000s, energy harvesting systems based on piezoelectric materials that convert mechanical energy into electrical energy have attracted a great deal of interest from the scientific community. The sources of mechanical energy targeted are fluids (air, water), vibrating structures (vehicles, industrial machinery) and even the human body. Among the piezoelectric materials studied, zinc oxide, in nanostructured form, emerged as a promising candidate because it is easy to synthesise, it is compatible with the European RoHS Directive and biocompatible. GREMAN laboratory, whose specificity is to address all stages, from modelling to the manufacture of these devices, including dedicated characterisation, has proposed an original design based on a nanowires/polymer composite on a rigid or flexible substrate.

This PhD thesis focuses on the operation of this type of nanogenerator and, more specifically, on the coupling of the piezoelectric and semiconducting properties of zinc oxide in a nanostructured configuration. Numerical simulations using a multiphysics model for the finite element method make it possible to better predict the consequences of variations in the various parameters on the voltage generated or the electrical energy harvested. This nanostructuring exacerbates surface properties compared with volume properties, such as the effect of surface traps on nanowires. In this context, modulations of the mechanical, piezoelectric and electrical properties need to be considered in order to gain a better understanding of the electrical response of the nanogenerator for a given mechanical excitation. This work shows that reducing the diameter of the nanowires increases their surface trap density and can lead to a factor of 100 increase in the voltage generated and a factor of 10 increase in the electrical energy recovered. Other elements, such as the choice of polymer and the geometrical properties of the composite, are studied in order to provide ideas for improving the manufacturing process. This work also shows the beneficial effect of a given nanowires density for a 1-3 piezocomposite to improve the mechanical-electrical coupling even in the case of piezo-semiconductor nanowires. Finally, an external electrical circuit capable of extracting the electrical energy converted by the nanogenerator is integrated into various simulations to deduce the optimum equivalent resistance for a given nanowires density on a given surface. The results for an active nanogenerator surface area of 1 cm^2 and a characteristic density of 40 nanowires/μm^2 give an optimum equivalent resistance of 100 $M\Omega$. In order to validate the simulation results experimentally and compare the performance of the nanogenerators, an experimental characterisation protocol is proposed. It uses a mechanical compression machine to create a controlled mechanical excitation and a dedicated electrical measurement circuit.