Improvement of Output from Triboelectric Nanogenerator in Intelligent Tire

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This study investigates the enhancement of triboelectric nanogenerators (TENGs) embedded within intelligent tires, aiming to improve their power output to a level sufficient for operating in-tire sensors. These sensors are vital for the development of autonomous vehicles, where constant monitoring of dynamic parameters such as friction coefficient, vehicle speed, tire pressure, and load is essential for stability, safety, and advanced control functions. Traditionally, intelligent tires equipped with sensors have faced limitations in power supply. Since embedded batteries are difficult to replace once depleted, there is a growing need for sustainable, self-powered solutions. Among various energy harvesting techniques, TENGs have gained attention for their lightweight, flexible, and low-cost nature, making them especially suitable for application in tires. However, earlier designs yielded relatively low power outputs—for example, only about 400 µW at a speed of 60 km/h—insufficient for supporting continuous wireless data transmission from sensors.

To address this issue, we proposed a comprehensive upgrade strategy involving three key components: (1) improvement of the triboelectric material, (2) optimization of the TENG structure, and (3) redesign of the power management circuit.

First, the triboelectric film materials were re-evaluated. In previous models, polyimide (PI) and polyamide (PA) films were used as the negative and positive charge materials, respectively. In the new design, porous polytetrafluoroethylene (PPTFE) was adopted as the negative triboelectric material due to its superior ability to generate negative charge based on its position in the triboelectric series. Additionally, the surface of the PPTFE film underwent air plasma treatment, introducing hydroxyl groups that significantly increased surface charge density. Comparative experiments showed that plasma-treated PPTFE produced more than four times the output voltage of untreated PPI, with the optimal plasma treatment duration determined to be approximately 180 seconds. Second, structural optimization of the TENG unit was undertaken. Parameters such as the TENG's physical length (LX) and the fixed distance between the friction surfaces (L) were varied and evaluated using a drum test rig to simulate real tire conditions. Results indicated that larger LX values generally yielded greater output, but structural limitations required careful balancing. The best-performing configuration featured a TENG length of 100 mm and a fixed distance of 140 mm. These dimensions allowed the upper plate to flex appropriately upon ground contact, maximizing energy generation. Third, the power management circuit—specifically the DC/DC step-down converter—was redesigned to accommodate the high-voltage, low-current characteristics of the improved TENG. Traditional converters operated only within a limited voltage range, restricting their effectiveness when dealing with the higher output voltages generated by the upgraded TENGs. New converter designs with adjustable threshold voltages (e.g., VL = 200 V, VH = 400 V) were introduced to efficiently store the harvested energy in capacitors without incurring voltage clipping or loss. Experimental results confirmed that the improved circuit significantly increased power delivery to the storage components.

To validate the effectiveness of these innovations, the researchers conducted both drum tests and real-vehicle tests. Five improved TENG units were installed inside a tire and tested at various speeds. The enhanced system demonstrated a peak power output of approximately 9 mW at 70–80 km/h—representing a twentyfold increase over the previous design's 400 µW at 60 km/h. This performance improvement strongly supports the feasibility of continuously powering wireless communication systems for in-tire sensors.

The study concludes that the integration of optimized triboelectric materials, structurally enhanced generators, and intelligent power management circuits greatly improves the practicality of using TENGs as power sources in intelligent tires. These developments contribute directly to the advancement of autonomous driving technology by enabling real-time monitoring of critical tire-road interaction parameters without the need for battery replacement or external wiring.