# Energy harvesting using obliquely aligned InN nanowire-based nanogenerators

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## Abstract

Piezoelectric materials such as ZnO and III-nitride are gaining increasing attention for their energy-related applications, including high-brightness light-emitting diodes (LEDs), full-spectrum solar cells, and nanogenerators. Because of the inconvenience of using chemical batteries to power wireless sensors, self-powered technologies that do not require batteries have emerged as attractive options in recent years. Harvesting energy from ambient mechanical movements in variable and uncontrollable environments is an effective method of powering wireless mobile electronics for a wide range of applications in everyday life. Piezoelectric nanowires are robust and can be stimulated by tiny physical disturbances over a range of frequencies. The operating principle of a nanowire-based nanogenerator involves the unique coupling of the piezoelectric and semiconducting properties and the gating effect of the Schottky barrier formed between metal tips and semiconductor nanomaterials. Consequently, nanogenerators convert mechanical energy from ambient movement into electricity that can be used to power nanodevices without batteries.

Group-III nitride materials, which are noted for their tunable, direct band gap and good chemical stability, are also characterized by pronounced piezoelectric properties because of their wurtzite crystal structure.[1] The calculated piezoelectric potentials increasing in the sequence of AlN, GaN, and InN lead to increasing levels of electricity generation, as observed in experiments.[1] Among all the group-III nitrides, InN possesses the smallest Young's modulus and the best conductivity for voltage output. Because of its unique piezoelectric properties, a single InN nanowire (NW) can generate an output voltage of up to 1 V, which is the highest voltage reported for this type of wire.[2] Although InN nanowires appear to be attractive for developing nanogenerators for self-powered nanodevices in the realm of nanoscience and nanotechnology, the most commonly employed structure consists of vertically aligned NW arrays dominating AC type nanogenerators. This design requires a rectifier to convert AC into DC output for self-powered nanodevices. Hence, more effort should be devoted to the highly oriented InN NW array to maximize the deformation and optimize the performance of DC nanogenerators. Therefore, this study not only extends piezotronics to a new domain using group-III nitrides, but also investigates the underlying physics of piezoelectric nanogenerators.

This study shows that output power can be harvested simply by exerting a normal force on a nanogenerator to create piezoelectric potential. The proposed nanogenerator consists of obliquely aligned InN nanorods that are deposited by glancing angle deposition with molecular beam epitaxy (Fig. 1).[3] This configuration maximizes the bending deformation produced by normal force, which is limited by the empty space between adjacent nanorods and the mechanical strength of the nanorods. Thus, this configuration enhances the piezoelectric potential and output power. This study investigates the surface- and force-dependent piezotronic characteristics by deflecting InN nanorods using a Pt/Ir tip of a conductive atomic force microscope. Under the influence of a strain-induced piezopotential, the Schottky barrier height increases for the compressed *c-plane* but decreases for the stretched *r-plane*. The Schottky barrier height of the *r-plane* is approximately 38 meV lower than that of the *c-plane* because of the existing surface electron accumulation layer. Therefore, the output current increases when the tip contacts the *r-plane* because of the Schottky barrier height lowering effect. Thus, the obliquely aligned InN nanowire-based nanogenerators convert mechanical energy into electric energy. The conversion mechanism relies on the coupling between the piezoelectric and semiconducting properties of InN by creating strain fields to drive the charge flow across the nanorods. The nanogenerators built on an InN nanowire array produce an average output direct current of 205.6 nA by modulating the Schottky barrier height under the influence of the surface electron accumulation layer. (Fig. 2) This study demonstrates the feasibility of using an obliquely aligned InN nanorod array to harvest electricity from the ambient environment, leading to the realization of self-powered nanodevices.

## References


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## Figures

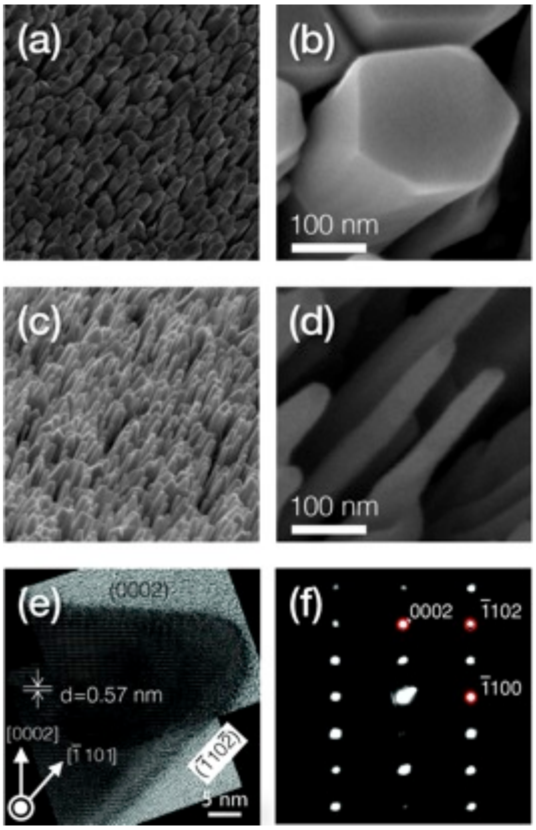


**Figure 1.** Tilted-view scanning electron microscopy images of (a, b) the thicker InN nanorod sample and (c, d) the thinner InN nanowire sample. (e) Cross-sectional transmission electron microscopy image of a single oblique InN nanorod with corresponding nanobeam electron diffraction pattern shown in (f).

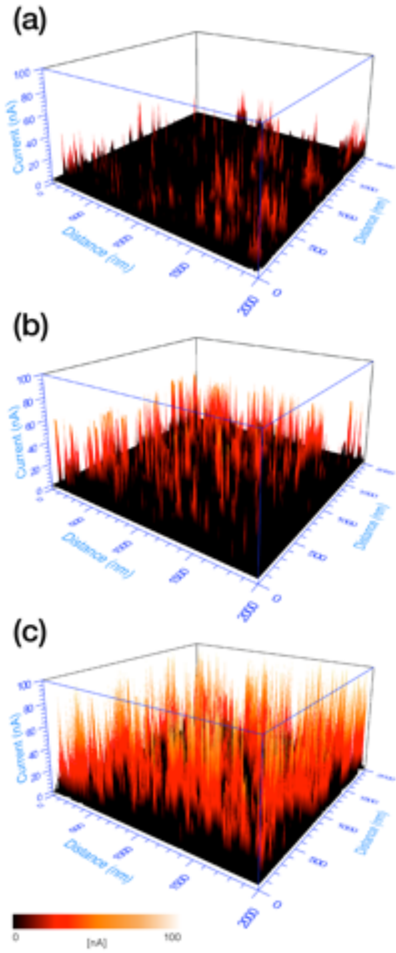


**Figure 2.** Current output image of the obliquely aligned InN NW array when the C-AFM tip scans across the NW array by (a) tapping mode, (b) contact mode with a tip force of 2nN, and (c) contact mode with a tip force of 3 nN.