

## Intrinsic nanostructures–semiconducting asymmetric nano-channel diodes

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Intrinsic nanostructures exhibit unique physical properties that are a direct consequence of their nano-scale parameters and the quantum mode of operation, in contrast to scaled down versions of well-known conventional devices. One of the best-known examples is a nonlinear, asymmetric nano-channel diode (ANCD), also called self-switching diode (SSD), invented in 2004 by Song *et al.* Unlike conventional, e.g., *p-n* diodes, the ANCD performance is not based on a vertical structure and the junction barrier, instead, it produces diode-like characteristics through nonlinear carrier transport in depletion-controlled nano-channel. The ANCD planar geometry allows for a flexible design and easy integration as multi-element sensors. Indeed, ANCDs have been demonstrated to be viable THz detectors and, based on Monte Carlo simulations, are expected to be efficient THz generators. We present our studies on fabrication and electrical and optical characterization of semiconducting ANCDs, focusing on the electron transport mechanism in a nano-channel, as well as their optical photoresponse. Our test devices were fabricated in InGaAs/InAlAs and GaAs/AlGaAs heterostructures with a 2-dimensional electron gas layer and patterned using electron beam lithography. Typical devices exhibit 250-nm-wide and 70-nm-deep trenches, defining a 2- $\mu\text{m}$ -long and 230-nm-wide nano-channel. The ANCD *I-V* curves collected in the dark showed nonlinear, diode-type behavior at all tested temperatures. Their forward-biased regions were well fitted to the classical diode equation with a thermionic barrier, using the ideality factor  $n$  and the saturation current as fitting parameters. In all of our devices, the impact of the light illumination was very clear, and there was a substantial photocurrent, even for incident optical power as low as 1 nW. The magnitude of the optical responsivity in ANCDs increased linearly over many orders of magnitude with the decrease of the optical power, reaching well above 1000 A/W at 1-nW excitation. This ultrahigh photoresponse was even further enhanced at low temperatures and at 78 K the responsivity was on the order of  $10^4$  A/W at nW-level optical excitation. The latter indicates that with the strongly suppressed dark current at low temperatures, cryogenic ANCDs look promising as candidates for single-photon-level optical detectors.

**Roman Sobolewski** is a Professor of Electrical and Computer Engineering, Physics, and Materials Science, as well as a Senior Scientist of Laser Energetics at the University of Rochester, Rochester, NY, USA. He received his Ph. D. and D. Sc. (Habilitation) degrees in Physics from the Polish Academy of Sciences, Warszawa, Poland, in 1983 and 1992, respectively. In 2006, he was granted the State Professorship of the Republic of Poland. In 2011, he received the Spanish Government Research Scholarship and spent a semester at University of Salamanca, Spain. In 2015, he was named a Distinguished Fellow of the Kosciuszko Foundation Collegium of Eminent Scientists of Polish Origin and Ancestry. In 2016, he was a Lecturer at the European Society of Applied Superconductivity Winter School on “Novel frontiers in superconducting electronics: from fundamental concepts and advanced materials towards future applications” in Pozzuoli, Italy. From 2009 till present he has been the Co-Chair and Co-Organizer of the Photon Counting Applications Conferences during the biennial SPIE Europe Optics+Optoelectronics Meeting in Prague, Czechia. Dr. Sobolewski’s current interests are concentrated on ultrafast phenomena in condensed matter, novel nanostructured electronic and optoelectronic semiconducting and superconducting materials and devices, single-photon quantum detection, and on generation and detection of THz radiation transients. He has published almost 400 peer-reviewed publications and presented well over 200 invited conference talks, lectures, seminars, and colloquia worldwide.