

Multiplexed, Label-Free InP Nanowire Photodetectors for Nanofluidic Single-Particle Sensing

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We demonstrate a label-free detection of single nanoparticles using individual InP nanowires integrated into nanofluidic chips. Nanochannels confine and guide liquid and particles, while nanowires transduce optical signals into electrical ones. A single nanowire resolves the transit of sub-micrometer particles as a transient dip in its photocurrent without fluorescent labels. A modular PCB readout setup is used to read the signal from the nanowires. This system has the potential to read multiple nanowires in parallel, which can be used in the future for multiplexing and to gain insights into particle characteristics, like size and flow speed.

InP nanowire, photodetector, nanofluidics, label-free detection, multiplexed readout.

Background, Motivation and Objective

Nanofluidic single-molecule analysis relies almost exclusively on fluorescence microscopy, which is limited to two optically aligned excitation spots per device and depends on fluorescent labelling of analytes [1]. Replacing this optical readout with an electrical one would eliminate alignment, remove labelling, and allow several sensing sites to be integrated along the same channel. Wafer-scale arrays of individually contacted InP p-i-n nanowires [2] enable a distributed electrical readout. We present a device in which nanowires, placed directly beneath a PMMA nanochannel, operate as label-free photoelectrical detectors of objects passing through the channel.

Device Concept

A single InP nanowire of 200 nm diameter contacted at both ends by Ti/Au builds a detection site. (Fig. 1) Shortage is prevented by a protective Al_2O_3 layer on top of the nanowire. A nanochannel is exposed directly above the nanowire by electron-beam lithography. The channel is sealed by a transparent polymer coverslip onto which microchannels and inlet holes have been transferred by UV-nano-imprinting [3].

Working Principle

Illumination from above generates photocarriers that drive a photocurrent. Transient changes in

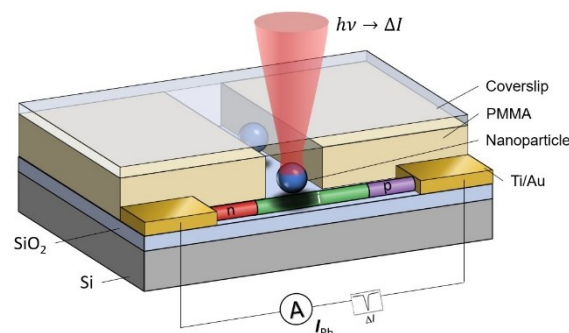


Fig. 1. Cross-section of the detection site. A 500 nm particle flowing through a $1 \times 1 \mu\text{m}^2$ PMMA nanochannel shadowing the laser. The InP p-i-n nanowire underneath produces a transient dip in the photocurrent. Each nanowire is individually contacted on both ends by Ti/Au contacts. The nanowire and contacts are covered with a 20 nm ALD Al_2O_3 layer to insulate from the analyte.

the photocurrent of then nanowire indicate a particle passing through the channel.

A two-board PCB readout addresses many detection sites in parallel. A microscope-slide-sized daughterboard holds the sample, with each nanowire wire-bonded to a PCB trace. A motherboard with BNC connectors accepts the daughterboard and routes each wire to its own measurement channel (Fig. 2). The modular format enables rapid sample exchange and parallel readout of several nanowires.

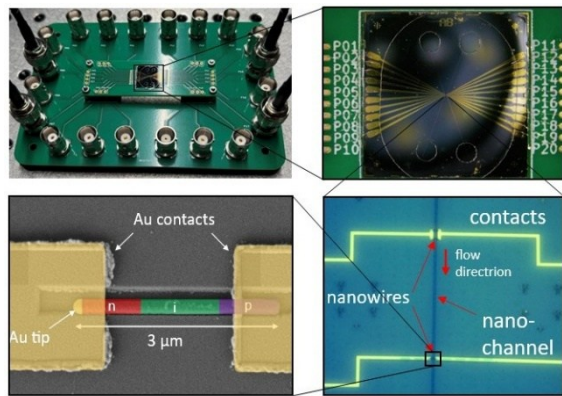


Fig. 2. Progressive zoom into the integrated sensor. From left to right: motherboard PCB with BNC outputs; daughterboard holding the wire-bonded sample; optical micrograph of the nanochannel crossing the nanowire array; and SEM of one nanowire contacted at n and p doped segment, nanochannel crosses perpendicular on top of the nanowire.

Results

Fig. 2 shows the device integration across different scales, from PCB to detection site.

The baseline photocurrent is stable under constant laser illumination and scales linearly with incident power (Fig. 3), consistent with the photoelectrical response reported for the same nanowire technology [2].

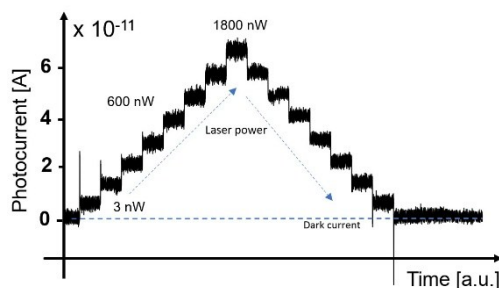


Fig. 3. Stepwise increase (3 nW → 1800 nW) and decrease of the incident laser power and the corresponding nanowire photocurrent. The current tracks the optical power in discrete, reversible steps and returns to the dark-current baseline, demonstrating the direct photoresponse of the contacted InP nanowire.

500 nm fluorescent polystyrene beads flown through the nanochannel produce each a transient dip in the nanowire photocurrent as they cross the illuminated region. Fig. 4 sketches the nanochannel at three consecutive time points (t_1 , t_2 , t_3) as a single bead travels through the laser spot above the nanowire. In the bottom Fig. 4 shows the corresponding photocurrent measurement. The dip reaches its minimum when the bead is directly over the wire (t_2) and recovers to baseline once the bead has left the focal spot (t_3). A simultaneous CCD recording confirms each dip corresponds to a single particle, not an electrical artefact.

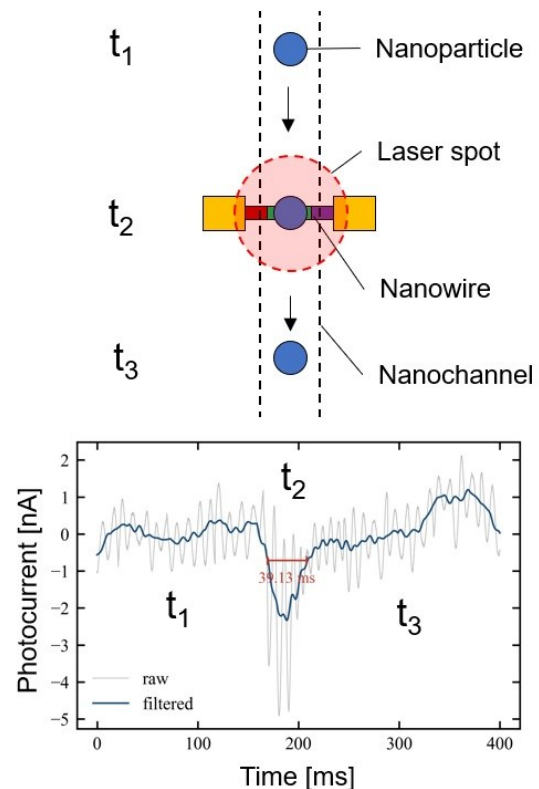


Fig. 4. (top) Sketch of a single nanochannel at three successive time points t_1 , t_2 , t_3 . A nanoparticle flows top-to-bottom through the laser spot, crossing the nanowire at t_2 . (bottom) Corresponding photocurrent trace (raw and filtered); the dip reaches its minimum at t_2 and recovers to baseline at t_3 . FWHM $\approx$ 39 ms.

The readout is label-free and wavelength-agnostic above the InP bandgap (~ 925 nm) because it depends only on optical modulation at the nanowire. Combined with the multi-channel PCB, this yields a multiplexed, label-free platform for nanofluidic analyte detection.

Ongoing work targets three directions: parallel readout of several nanowires under one channel for on-chip time-of-flight velocimetry; channel geometries adapted to biomolecules; and full characterization of responsivity and noise floor using a supercontinuum source.

References

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