Macroscopic Assembly of Indefinitely Long and Parallel Nanowires into Large Area Photodetection Circuitry

Ozan Aktas[1,3,*], Erol Ozgur[1,2], Mehmet Bayındır[1,2,3]
[1]*UNAM-National Nanotechnology Research Center, Bilkent University, 06800 Ankara, Turkey*
[2]*Institute of Materials Science and Nanotechnology, Bilkent University, 06800 Ankara, Turkey*
[3]*Department of Physics, Bilkent University, 06800 Ankara, Turkey*
***email:** aktaso@bilkent.edu.tr*

Abstract: We demonstrate a novel fabrication technique of a photodetection circuitry with light sensitive pixels consisting of hundreds of long and parallel selenium nanowires. Using 10x10 pixel format, alphabetic characters were identified by the nanowire circuitry.
OCIS codes: (040.5160) Photodetectors; (160.1890) Detector materials; (220.4241) Nanostructure fabrication.

Despite their unusual and promising physical properties, large scale utilization of nanowires could not be satisfactorily accomplished to date due to their extremely small dimensions hindering their manipulation or inevitable as-produced state having random or irrelevant orientation. Nanowire integration strategy is strongly depended on the production technique. For example in top-down nanowire fabrication, lithography and etching enable wafer-scale aligned nanowires with high densities and precisely defined locations [1]; for bottom-up nanowire fabrication directional flow of the liquid through microfluidic channels [2], compressing nanowires on a Langmuir−Blodgett trough [3], or applying electric field can be used to align nanowires on predetermined positions[4], and integrate them into functional devices.

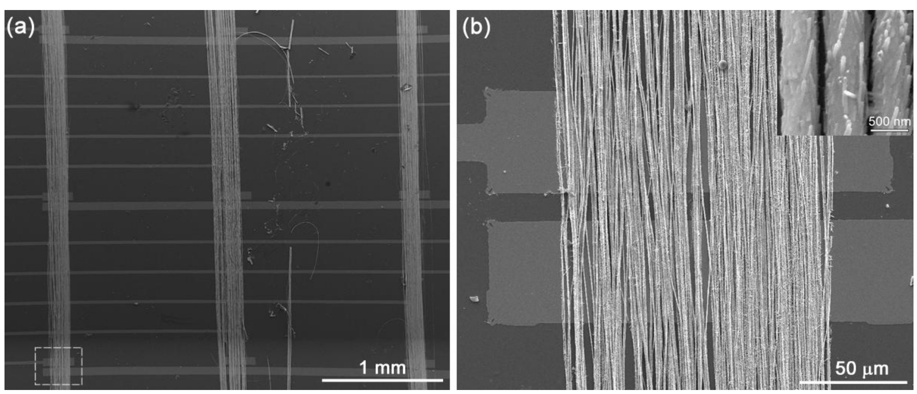

Fig.1. (a) Electron microscopy image of crystallized selenium nanowires lying over ground and readout electrodes of the lithographically defined circuitry. (b) SEM image of a single pixel, composed of hundreds of photoconductive selenium nanowires aligned over electrode pairs. A high-resolution SEM image of NW arrays can be seen in the inset.

In this work [5], we demonstrated a macrofabrication of nanowire-based photodetection device using long and polymer encapsulated selenium nanowire arrays produced by a recently developed nanofabrication technique of iterative thermal size reduction [6]. By manual alignment of the encapsulating fibers that contain hundreds of individual nanowires, controlled etching of the polymer encapsulation and then crystallization using organic solvents, parallel nanowire arrays were integrated onto a lithographically patterned circuitry chip to form photoconductive pixels as shown in Fig. 1a. Fig. 2b. is a detailed image of a single pixel, composed of hundreds of parallel selenium nanowires over pixel electrode pairs.

In order to utilize resulting structure as a sensing part of an imaging device, first of all, we investigated photoconductive properties of each pixel under dark, constant, and on−off modulated illumination with a broadband light source. Pixels have slightly different responses to the same light intensity due to the fabrication ambiguities such as number of active nanowires in contact with electrode pairs and electrical contact quality. Distribution of pixel photosensitivity shows that majority of functional pixels has almost the same sensitivity except for a few highly sensitive and insensitive pixels.

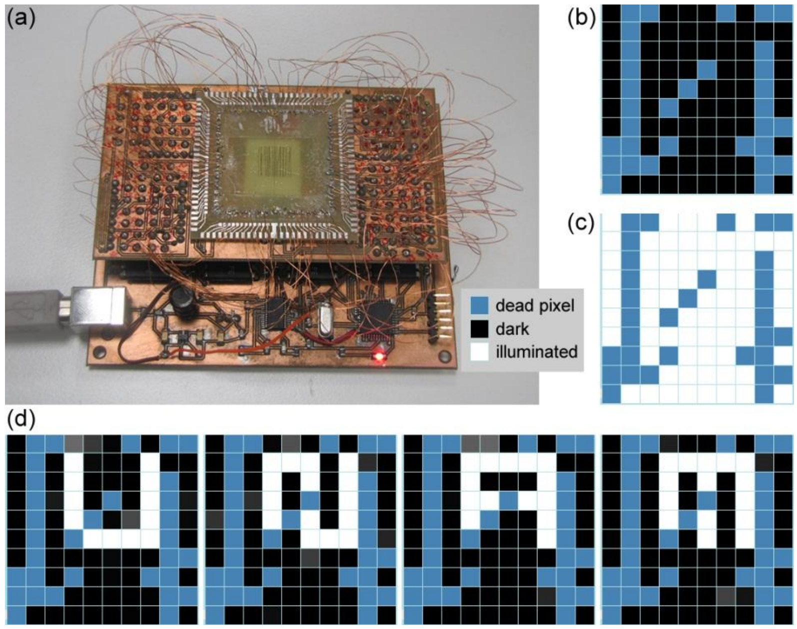

Fig.2.(a) Assembled selenium nanowires on photodetection circuitry and custom-made readout electronics. (b) Software constructed image of 10 × 10 pixels after full exposure of the device to a light source for static dark and (c) bright illumination. (d) Images of dark field iluminated alphabetic characters of "UNAM" captured by nanowire based pixel array. Blue pixels are dead pixels.

To use a circuitry composed of nanowire-based pixel arrays as an imaging device, the photoconductive response of each pixel needs to be calibrated and converted into a grayscale pixel color of a constructed image. For this purpose, we designed custom readout hardware for photodetection circuitry and developed application software for image construction (Fig. 2a). Photoconductive responses of every pixel in the 10 × 10 array as a voltage signal were sampled by analogue multiplexers, 10 bit digitized, and converted to 8 bit grayscale color values. Full exposure of the device to static dark and bright illumination with calibrated pixels is shown in Fig. 2b and Fig. 2c, respectively. Blue pixels denote dead pixels, which are found to be poorly sensitive or completely insensitive to the light as a result of broken metal lines produced by lift-off process or poor electrical contact formation between nanowires and pixel electrodes due to misalignment of the fibers. Using close contact masks, dark field illumination of some characters can be projected on the pixel array and captured by the software as images of alphabetic characters shown in Fig. 2d. The device is 68% functional.

The macroscopic alignment procedure used here resulted in functionalization of semiconducting nanowires as a large area functional device. Employment of thermally drawn nanowires with a macroscopic alignment approach might pave the way for very interesting occasions where nanoscale and macroscale are effectively bridged. Some possible routes toward utilization of this technique might be fabrication of nanowire thin film transistor columns, integration of phase change nanowires into various memory circuitries such as cross-bar structures, fabrication of large scale nanowire-based thermal sensors, or artificial skin and muscle. Also, integrating nanowires onto flexible or curved surface device geometries or efficiently aligning very long core−shell nanostructures for photonic and photovoltaic applications would be possible.

[1] N. A. Melosh, A. Boukai, F. Diana, B. Gerardot, A. Badolato, P.M. Petroff, J.R. Heath," Ultrahigh-Density Nanowire Lattices and Circuits," Science, **300**, 112−115(2003).
[2] Y. Huang, X. Duan, Q. Wei, and C. Lieber, "Directed assembly of one dimensional nanostructures into functional networks," Science, **291**, 630-633(2001).
[3] D. Whang, S. Jin, Y. Wu, C.M. Lieber, "Large-Scale Hierarchical Organization of Nanowire Arrays for Integrated Nanosystems," Nano Lett., **3**,1255−1259 (2003).
[4] P.A. Smith, C.D. Nordquist, T.N. Jackson, T.S. Mayer, B.R. Martin, J. Mbindyo, T.E. Mallouk," Electric-field assisted assembly and alignment of metallic nanowires," Appl. Phys. Lett., **77**, 1399−1401(2000).
[5] E. Ozgur, O. Aktas, M. Kanık, M. Yaman, M. Bayindir, "Macroscopic Assembly of Indefinitely Long and Parallel Nanowires into Large Area Photodetection Circuitry," Nano Lett., **12**, 2483−2487 (2012).
[6] M. Yaman, T. Khudiyev, E. Ozgur, M. Kanik, O. Aktas, E. O. Ozgur, H. Deniz, E. Korkut, M. Bayindir, "Arrays of indefinitely-long, uniform nanowires and nanotubes," Nat. Mater., **10**, 494−501 (2011).