Template-based surface nano-patterning to realize high performance devices

Liaoyong Wen\textsuperscript{1,2}, Huaping Zhao\textsuperscript{1,2}, Fabian Grote\textsuperscript{1,2}, Yan Mi\textsuperscript{1,2}, Ranjith Vellacheri\textsuperscript{1,2}, Zhibin Zhan\textsuperscript{1,2}, Ahmed Al-Haddad\textsuperscript{1,2}, Yaoguo Fang\textsuperscript{1,2}, Kin Mun Wong\textsuperscript{1,2}, Yong Lei\textsuperscript{1,2,}\textsuperscript{*}

\textsuperscript{*} yong.lei@tu-ilmenau.de

\textsuperscript{1}Fachgebiet 3D-Nanostrukturierung, Institut für Physik & IMN (Zentrum für Innovationskompetenz, MacroNano\textsuperscript{®}), Technische Universität Ilmenau, Heliosbau 1102, Prof. Schmidt-Straße 26, 98693 Ilmenau.

\textsuperscript{2}Institut für MaterialPhysik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany
Surface patterns in nature

Structural color – function of surface patterns

- Butterfly
- Peacock

Packing of melanin cylinders (provided by L Chi)
Surface patterns and structures (artificial) and their applications in diverse (micro-electronic) devices

Images from the open source:
What is an excellent surface nano-patterning technique?

1. Ability to prepare surface patterns within the nanosized range;
2. Well-defined surface nano-patterns;
3. Large pattern area – high throughput;
4. A general process – applicable;
5. Low cost.

Surface Nano-Patterning

Fabrication of surface nanostructures

Conventional nano-patterning techniques

- Electron-beam lithography
  - Excellent structural controlling
  - Low throughput
  - High equipment costs

- Imprint technologies
  - High throughput
  - Wear
  - Structures with low aspect ratio

- Self assembly
  - Low costs
  - High throughput
  - Limited class of materials
  - Low structural controlling

⇒ Alternative method that combines these advantages and is applicable for a broad range of surface nanostructures?

UTAM (ultra-thin alumina mask) surface nano-patterning

Two-dimensional surface nano-patterning

Ultra-Thin Alumina Mask, a special porous alumina template

Two-dimensional surface nano-patterning

Two-dimensional surface nano-patterning

UTAM is a efficient tool to adjust the nanoparticles array shape, size and distance

A challenging technical point
for UTAM technique to realize quantum-sized surface structures (below 10 nm)

Well-controlled wet etching process to the barrier layer of UTAMs
realizing pore-opening and surface nanostructures within the quantum-sized range

Small 2010, 6 (5), 695-699.
Two-dimensional surface nano-patterning

Small 2010, 6 (5), 695-699.

Wet etching process

~5 nm

~ 10 nm

~ 17 nm
Two-dimensional surface nano-patterning

Quantum dot array

Small 2010, 6 (5), 695-699.
Tunable properties of surface patterns based on the adjustment of the structural parameters


3. Ordered arrayed metal oxide nanodots with the similar size, shape, crystalline structure and orientation. This work is a step towards the goal of achieving iso-nanoparticle arrays and full property tuning. (Y Lei, et. al., Nanotechnology, 16, 1892, 2005).


5. DPG Conference, AKE 13.3 Wed 17:30 EW 201 Speaker: Zhibing Zhan Research of photocatalytic mechanism using tunable metal/semiconductor nanosized heterostructures
Addressing System for 3-D surface nano-patterns
large-scale (mm$^2$ - cm$^2$) with nano-scale resolution

Schematic of the addressing system (only shows an array of 3 × 3)
Addressing System for 3-D surface nano-patterns
large-scale \(\text{mm}^2 - \text{cm}^2\) with nano-scale resolution

A device based on 3-D surface nano-structures with addressing system (for a 1 mm\(^2\) area of 3-D surface nano-patterns with pattern spacing of 100 nm, the addressing system has 10000 lines for each set of electrodes. Totally \(10^8\) nano-units can be addressed
Pre-patterned Large Square Nanopore Arrays
On Aluminum and Silicon Substrates
Three-Dimensional Surface Nano-Patterning: Concepts, Challenges and Applications

ZnO nanotubes array for gas sensor

UTAM + ALD Process
The sensitivity of the sensor to NO$_2$ gas could reach to less than 25 ppb, which has never been achieved before for commercial gas sensors.
Three-Dimensional Surface Nano-Patterning: Concepts, Challenges and Applications

Novel ultra-long ZnO nanowires array for flexible Schottky diodes

ZnO Schottky diodes fabrication process

Firstly, using the UTAM techniques, we successfully achieved different kind of surface nano-patterning, including two-dimensional nanopartiles array and three dimensional nanowire/nanotube array.

Secondly, all those nano-patterning’s structures and properties can be easily controlled according to the template’s pore size and aspect ratio.

Thirdly, the surface nano-patterning can be widely used in highly performance device, such as memory device, gas sensor, bio-sensor and also other kind of energy devices.---------On the way!

DFG conference, O 76.6 Thu 17:15 MA 042. Talker: Fabian Grote
High performance super-capacitors based on template-prepared one dimensional MnO2 nanostructures
Acknowledgements

Surface Nano-Structuring Group

**Group Leader:** Prof. Dr. Yong Lei

**Group Members:**

**Scientists:**
- Dr. Huaping Zhao
- Dr. Kinmun Wong
- Dr. Hongjun Chen
- Dr. Zhibing Zhan
- Dr. Chengliang Wang

**PhD candidates:**
- Fabian Grote
- Ahmed Shukur Hameed Al-Haddad
- Yaoguo Fang
- Yan Mi
- Ranjith Vellacheri
- Wenxin Wang
- Felix Stosberg
Thanks for your attention!