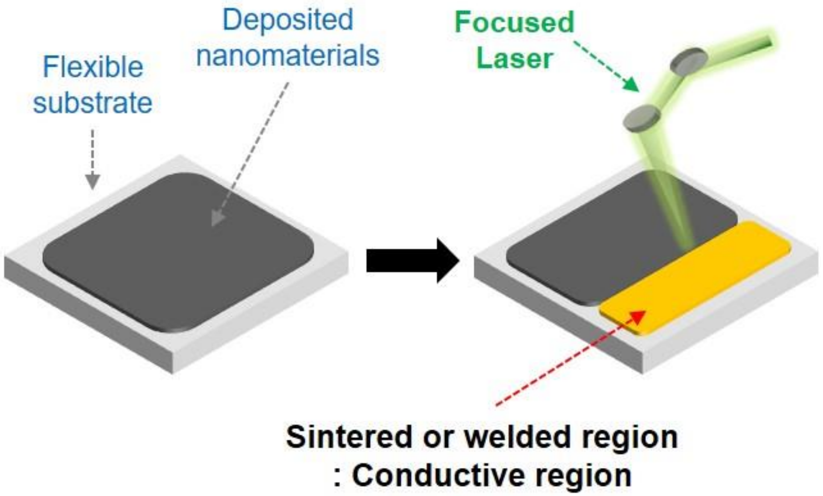
Laser nano processing

Interaction : Light -> Materials

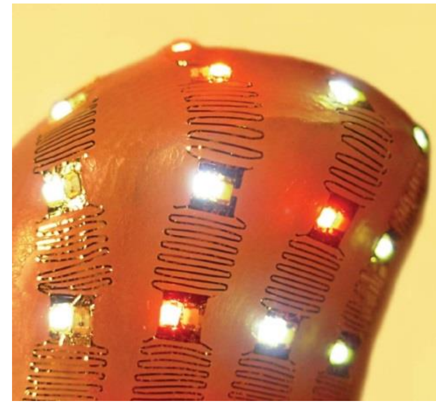


Wearable electronics

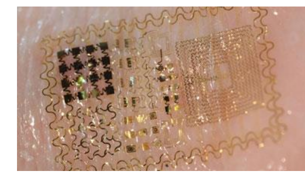
What will be happen in the future

reload4btech.blogspot.com

Wearable electronics



Stretchable LED
[Rogers group, UIUC]



Stretchable sensors
[Rogers group, UIUC]

Problem: Forming <u>high melting temperature metal</u> film/pattern on low melting temperature substrate without <u>thermal damage</u>.

Low temperature process is the most important technology !!!

Solution: Low temperature process development
(1) Nanomaterial (size dependent thermal property, $T_{melting}$ drop)
(2) Laser as localized heat sources (reduced HAZ)

Novel Applied Nano Optics (NANO) lab

Professor : Junyeob Yeo

Assistant Professor
Novel Applied Nano Optics (NANO) lab,
Department of Physics, Department of Hydrogen and Renewable Energy,
Kyungpook National University,
80 Daehak-ro, Bukgu, Daegu 41566, Republic of Korea
Tel: +82-53-950-7360 / Fax: +82-53-952-1739
sites.google.com/site/junyeob

PhD student

Kong, Heejung

Master students

Hwang, Tae Seung

Hwang, Suwon

Yang, Hae Chang

Undergraduate students: Lee, Heejin Kim, Hyunwoo Park, Seokyoung

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NANO Lab.
Novel Applied
Nano Optics Laboratory

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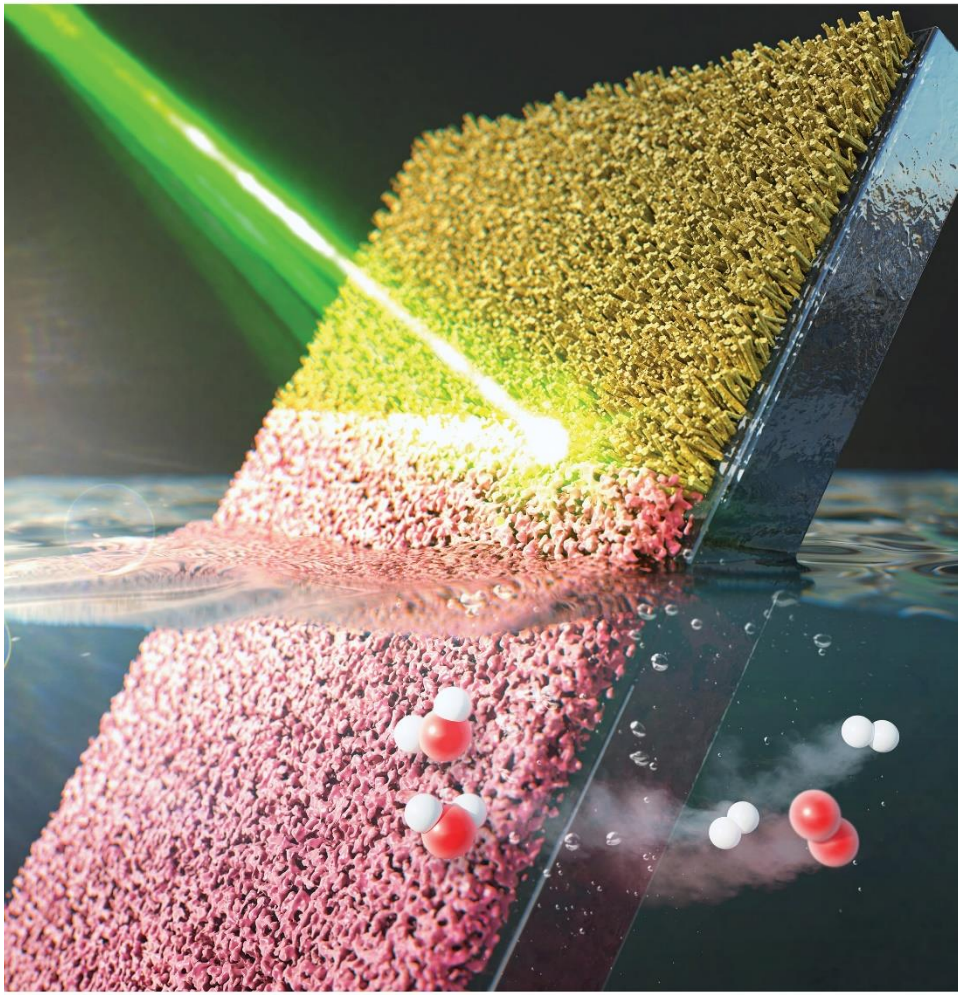

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ACS APPLIED MATERIALS & INTERFACES

www.acsami.org Research Article

Laser-Induced Crystalline-Phase Transformation for Hematite Nanorod Photoelectrochemical Cells

Heejung Kong,○ Jinhyeong Kwon,○ Dongwoo Paeng, Won Jun Jung, Santosh Ghimire, Joonghoe Dho, Jae-Hyuck Yoo, Sukjoon Hong, Jinwook Jung, Jaeho Shin, Costas P. Grigoropoulos,* Seung Hwan Ko,* and Junyeob Yeo*

Cite This: ACS Appl. Mater. Interfaces 2020, 12, 48917−48927 Read Online

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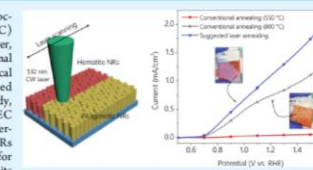
ABSTRACT: Generally, a high-temperature postannealing process is required to enhance the photoelectrochemical (PEC) performance of hematite nanorod (NR) photoanodes. However, the thermal annealing time is limited to a short duration as thermal annealing at high temperatures can result in some critical problems, such as conductivity degradation of the fluorine-doped tin oxide film and deformation of the glass substrate. In this study, selective laser processing is introduced for hematite-based PEC cells as an alternative annealing process. The developed laser-induced phase transformation (LIPT) process yields hematite NRs with enhanced optical, chemical, and electrical properties for application in hematite NR-based PEC cells. Owing to its improved properties, the LIPT-processed hematite NR PEC cell exhibits an enhanced water oxidation performance compared to that processed by the conventional annealing process. As the LIPT process is conducted under ambient conditions, it would be an excellent alternative annealing technique for heat-sensitive flexible substrates in the future.



KEYWORDS: *hematite nanorod, laser, laser-induced phase transformation, water splitting, photoelectrochemical cell*

1. INTRODUCTION

Hematite (α-Fe_2O_3) is one of the most abundant metal oxides in nature and a thermodynamically stable phase among iron oxides. Besides, it has interesting properties, such as n-type semiconducting characteristics, low toxicity, magnetic behavior, and a visible-range band gap of ~2.0 eV.[1] Owing to these properties, hematite has attracted significant interest for application in various electronic and energy devices, including sensors,[2] lithium-ion batteries,[3] photocatalysts,[4] and photoelectrochemical (PEC) cells.[5,6] Among the various applications of hematite, PEC cells have been extensively studied because of their band gap, which is suitable for achieving the maximum theoretical solar-to-hydrogen (STH) efficiency of 16.8%.[7]

However, previous studies[8−10] on hematite-based PEC cells recorded considerably lower STH efficiency than the theoretical prediction. This low efficiency is attributed to the inherent limiting properties of hematite, such as short carrier lifetime,[11,12] short charge-carrier diffusion length,[13] and sluggish oxygen evolution reaction (OER) kinetics.[14] Hence, in an attempt to overcome these limitations, many researchers have employed techniques such as nanostructure engineering to increase the effective surface area,[5,6,15−17] functional element doping or oxygen vacancy engineering to improve the donor density,[9,10,18−20] heterojunction fabrication for efficient charge separation,[21] surface-state passivation to reduce surface recombination,[22,23] and cocatalyst deposition to boost the OER.[24−26]

Since the report by Vayssieres et al. on the growth of vertically aligned hematite nanorods (NRs) on a fluorine-doped tin oxide (FTO) film *via* hydrothermal synthesis,[27] several studies have been conducted on hematite NR photoanodes for solar water splitting.[28−31] Hematite NRs grown *via* hydrothermal synthesis always require a postannealing process to change the crystalline phase from the as-grown akaganeite (β-FeOOH) to hematite. The conventional annealing process using convection ovens or electric furnaces is usually conducted at high temperatures (over 550 °C) and for a long period (over 2 h). However, the obtained hematite NRs still exhibit poor PEC performance compared to the theoretically predicted value. Thus, various alternative thermal annealing processes have been proposed to enhance the PEC performance. However, most of these incur challenges, such as

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Length-dependent photo-electrochemical performance of vertically aligned hematite nanorods

Heejung Kong [a], Jinjoo Jung [b], Suwon Hwang [a], Jaemin Park [a], Do Hyung Kim [b], Junyeob Yeo [a,c,*]

[a] Novel Applied Nano Optics Lab. Department of Physics, Kyungpook National University, 80 Daehak-ro, Bukgu, Daegu, 41566, Republic of Korea
[b] Nano Applied Physics Lab. Department of Physics, Kyungpook National University, 80 Daehak-ro, Bukgu, Daegu, 41566, Republic of Korea
[c] Department of Hydrogen and Renewable Energy, Kyungpook National University, 80 Daehak-ro, Bukgu, Daegu, 41566, Republic of Korea

ARTICLE INFO

Keywords:
Hematite
Hydrothermal synthesis
Vertically aligned nanorods
Photo-electrochemical cell
Cobalt phosphate cocatalysts

ABSTRACT

Photo-electrochemical (PEC) cells have been widely studied as an eco-friendly method of producing hydrogen fuel. Among the various materials, hematite (α-Fe_2O_3) is one of the most promising candidates for PEC applications due to its chemical stability and visible-range bandgap. However, despite the aforementioned advantages, hematite-based PEC cells have suffered from an extremely short hole diffusion length and charge carrier lifetime, resulting in a solar-to-hydrogen efficiency far lower than the theoretical maximum. To overcome these drawbacks, we controlled the length of vertically aligned hematite nanorod (NRs) arrays on a fluorine-doped tin oxide substrate by adjusting the chemical concentrations of the precursor solutions. We confirmed that the PEC performance of the hematite NRs was strongly dependent on their length and showed an approximately inverse proportionality between the length of the hematite NRs and their photoactivity. In addition, the hematite NRs array, with an optimized length, was further modified by cobalt phosphate (Co-Pi) cocatalysts to enhance the water oxidation kinetics and showed 1.54 mA cm^{-2} of photocurrent at 1.23 V vs. RHE.

1. Introduction

Over the last several decades, interest in renewable and sustainable energy as a replacement for fossil fuels has gradually increased. Among the renewable energy sources, hydrogen emits no greenhouse gases during burning and is therefore regarded as one of the most promising candidates for replacing these fuels. Commercial hydrogen gas is usually extracted from fossil fuels such as petroleum, coal, and natural gas. However, these extraction processes are not eco-friendly and therefore, electrolysis and photo-electrolysis of water have received considerable interest as possible alternative processes of hydrogen gas production. Thus, since the development of the first photo-electrochemical (PEC) cell using TiO_2 [1], various semiconductor materials (e.g., α-Fe_2O_3 [2–4], WO_3 [5,6], TiO_2 [7,8], and ZnO [9,10]) have been investigated as PEC cells for hydrogen fuel production.

Hematite (α-Fe_2O_3) is an earth-abundant, non-toxic, and thermally stable n-type semiconductor material with a visible optical bandgap (1.9–2.2 eV) [11–13]. In addition, the most frequent photon energy in the atmosphere of the Earth (1.6–2.4 eV) lies in the range defining the bandgap of hematite. Due to these attributes, hematite has been widely studied as a photoanode in the PEC cell [2–4,14–19]. The performance of the hematite-based PEC cell is, however, inferior compared with the solar to hydrogen efficiency (15%), due to its short hole diffusion length (2–4 nm) [20] and short charge carrier lifetime [21,22].

Considering these poor charge carrier properties of hematite, reducing the film thickness may be helpful for efficient water oxidation because this process occurs at the semiconductor material/electrolyte interface. The photo-generated electrons in an n-type semiconductor (like hematite) usually migrate to the metal cathode and induce the reduction of hydrogen ions, whereas holes contribute to the oxidation of water molecules at the interface. In the case of hematite, owing to the short hole diffusion length, only holes generated near the interface can contribute to the redox reaction. In this regard, a nano-sized thin layer of hematite can be beneficial for efficient water oxidation. A nano-sized thin layer of hematite shows, however, low photon absorption due to the considerable difference between the layer thickness and the

* Corresponding author. Novel Applied Nano Optics Lab. Department of Physics, Kyungpook National University, 80 Daehak-ro, Bukgu, Daegu, 41566, Republic of Korea.
E-mail address: junyeob@knu.ac.kr (J. Yeo).

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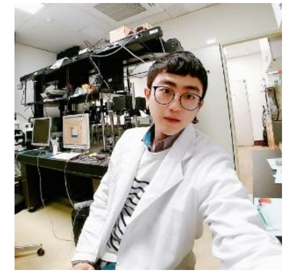
Available online 22 April 2020

materials



Article

Fabrication of Soft Sensor Using Laser Processing Techniques: For the Alternative 3D Printing Process

Myeongjoo Seo, Suwon Hwang, Taeseung Hwang and Junyeob Yeo *

Novel Applied Nano Optics (NANO) Lab, Department of Physics, Kyungpook National University, 80 Daehak-ro, Bukgu, Daegu 41566, Korea; seomyeong@knu.ac.kr (M.S.); suwonnn@knu.ac.kr (S.H.); ghkdxotmd@knu.ac.kr (T.H.)
* Correspondence: junyeob@knu.ac.kr

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Abstract: Recently, the rapid prototyping process was actively studied in industry and academia. The rapid prototyping process has various advantages such as a rapid processing speed, high processing freedom, high efficiency, and eco-friendly process compared to the conventional etching process. However, in general, it is difficult to directly apply to the fabrication of electric devices, as the molding made by the rapid prototyping process is usually a nonconductive polymer. Even when a conductive material is used for the rapid prototyping process, the molding is made by a single material; thus, its application is limited. In this study, we introduce a simple alternative process for the fabrication of a soft sensor using laser processing techniques. The UV laser curing of polymer resin and laser welding of nanowires are conducted and analyzed. Through the laser processing techniques, we can easily fabricate soft sensors, which is considered an alternative 3D printing process for the fabrication of soft sensors.

Keywords: laser; resin polymer; UV laser curing; laser nano welding; 3D printing process

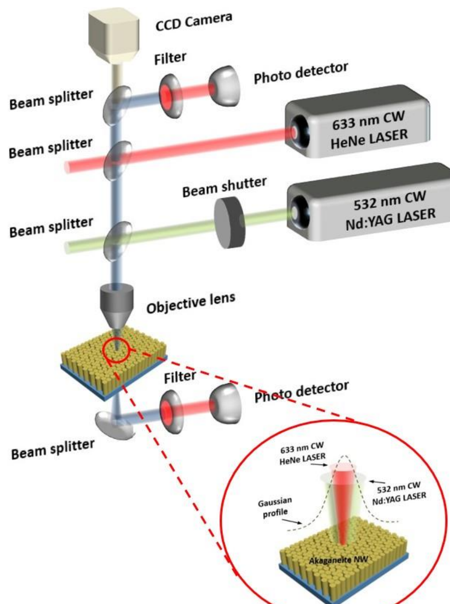
1. Introduction

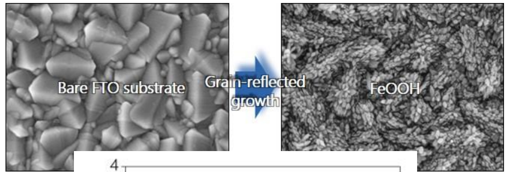
In the fourth industrial era, the importance of sensors that provide data for artificial intelligence in the Internet of Things (IoT) has progressively increased. Among the various sensor types, soft sensors for wearable devices [1–6] have received huge interest from both industry and research fields with the growth of the healthcare system market. Thus, the technology for the fabrication of soft sensors is also becoming more important.

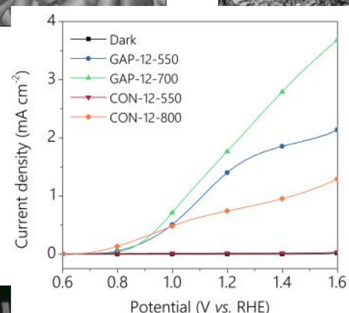
In conventional fabrication processes for elastomer-based soft sensors [7–10], those processes usually require a high proficiency due to the complex process steps. In addition, there are disadvantages such as an inconsistent and monotonous sensor structure, which originate from manual manufacturing. Thus, various processing techniques have been introduced to the fabrication of soft sensors.

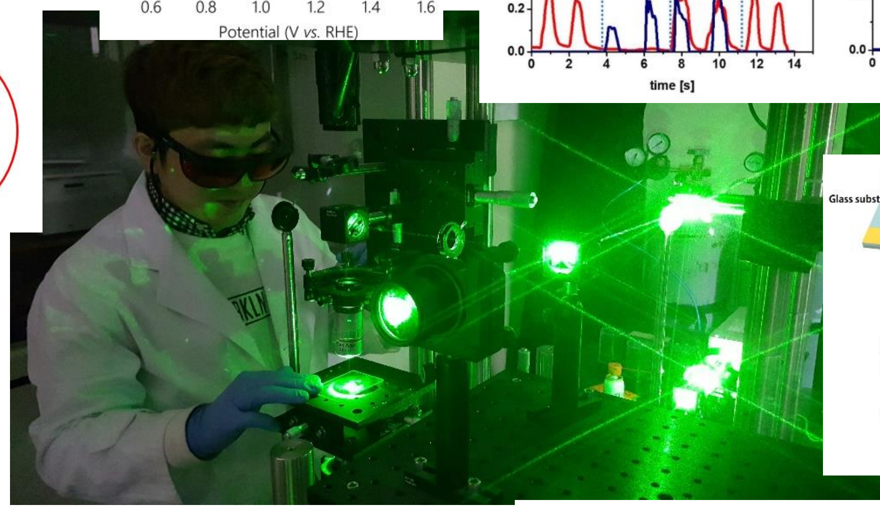
The rapid prototyping (RP) process [11,12] is one of the most promising processes for the fabrication of soft sensors. The RP process has various advantages such as a consistent and diverse structure. In addition, the RP process enables the fabrication of complex and sophisticated three-dimensional (3D) structures. Thus, research on thinner and delicate high resolutions by the RP process was actively carried out, recently [13]. However, the RP process is not impeccably suitable for the fabrication of soft sensors, as materials available for the RP process are limited [14]; thus, it is difficult to pattern the polymer body and metal electrode, simultaneously.

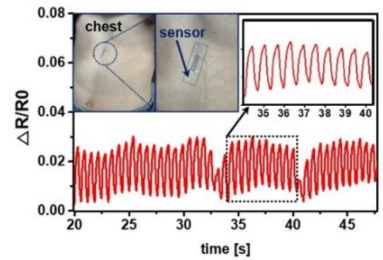
Among various RP processes, the laser processing technique is one of the first methods employed and the most representative method in the RP process. Depending on the type of material used, the laser processing technique in the RP process is usually classified by the stereo-lithography (SLA) process for polymer resin [15], selective laser sintering (SLS) for metal nano particles [16], and selective

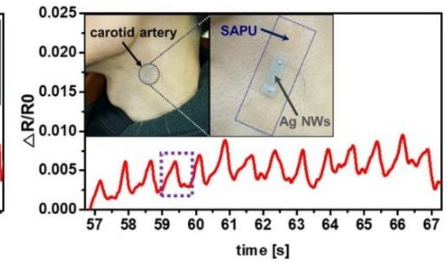

CCD Camera
Filter
Photo detector
Beam splitter
633 nm CW HeNe LASER
Beam splitter
Beam shutter
Beam splitter
532 nm CW Nd:YAG LASER
Objective lens
Filter
Photo detector
Beam splitter
633 nm CW HeNe LASER
532 nm CW Nd:YAG LASER
Gaussian profile
Akaganeite NW

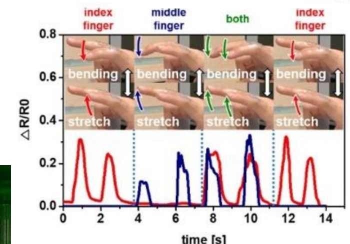

Bare FTO substrate
Grain-reflected growth
FeOOH

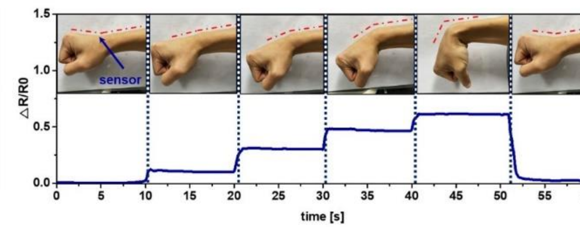

Dark
GAP-12-550
GAP-12-700
CON-12-550
CON-12-800
Current density (mA cm^{-2})
Potential (V vs. RHE)

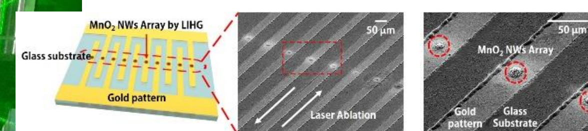


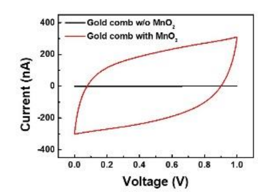

chest
sensor
△R/R0
time [s]

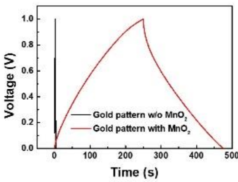

carotid artery
SAPU
Ag NWs
△R/R0
time [s]

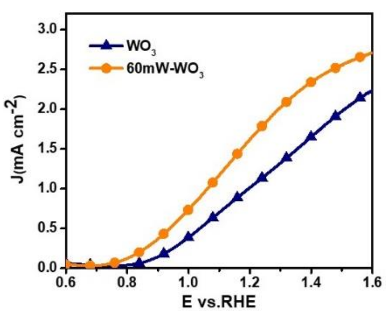

index finger
middle finger
both
index finger
bending
stretch
△R/R0
time [s]

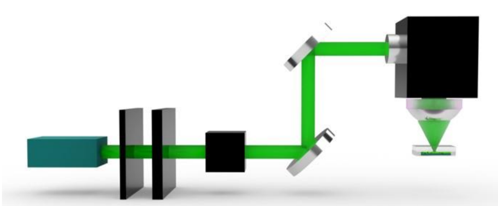

sensor
△R/R0
time [s]

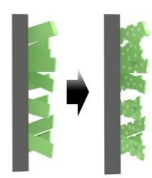

MnO$_2$ NWs Array by LIHG
Glass substrate
Gold pattern
50 μm
Laser Ablation
MnO$_2$ NWs Array
Gold pattern
Glass Substrate

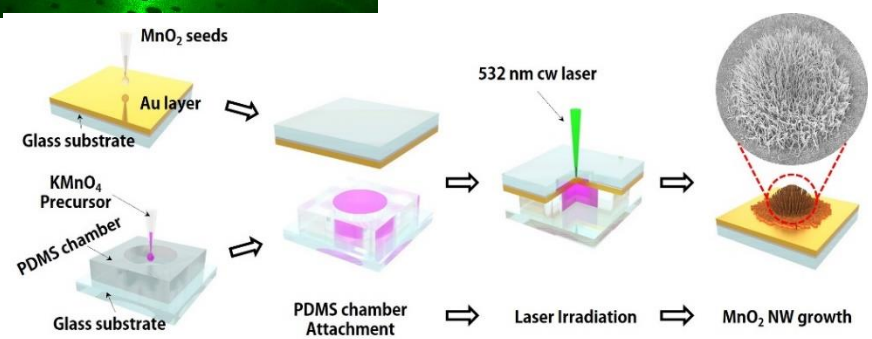

Gold comb w/o MnO$_2$
Gold comb with MnO$_2$
Current (nA)
Voltage (V)


Gold pattern w/o MnO$_2$
Gold pattern with MnO$_2$
Voltage (V)
Time (s)


WO$_3$
60mW-WO$_3$
J(mA cm^{-2})
E vs.RHE






MnO$_2$ seeds
Au layer
Glass substrate
KMnO$_4$ Precursor
PDMS chamber
Glass substrate
PDMS chamber Attachment
532 nm cw laser
Laser Irradiation
MnO$_2$ NW growth