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Sensing at terahertz frequency domain using a sapphire whispering gallery mode resonator

C. Mathai, Ravikumar Jain, V. G. Achanta, S. P. Duttagupta, D. Ghindani, N. R. Joshi, R. Pinto, and S. S. Prabhu

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Abstract

In this Letter, we experimentally demonstrate a terahertz (THz) whispering gallery mode (WGM) sensor based on a sapphire WGM resonator. The fundamental mode at 129.49 GHz with a Q-factor of 4.63×10^3 is used to study its sensitivity to adsorbed molecules. The efficiency of our sensor to detect rhodamine 6G dye molecules in a polyvinyl alcohol matrix at room temperature has been manifested, and a detection sensitivity of 25 parts per million has been achieved. Also, we report an analytical approach based on coupled-mode theory between the waveguide mode and the spherical resonator mode to evaluate the absorption coefficient of the adsorbed molecule on the resonator. The model is modified to evaluate optical constants of materials. The results obtained have been verified by continuous-wave THz transmission results. The results are of importance in sensing, metrology, and material characterization.

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Alva's Institute of Engg. & Technology
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Low frequency piezoelectric P(VDF-TrFE) micro-cantilevers with a novel MEMS process for vibration sensor and energy harvester applications

Rashmi K R[1], Arjun Sunil Rao[2], Jayarama A[1] and Richard Pinto[2]

[1] Department of Physics, Alva's institute of Engineering and Technology, Moodbidri, Karnataka, India
[2] Department of Electronics and Communication Engineering, Alva's institute of Engineering and Technology, Moodbidri, Karnataka, India

E-mail: rashmi.kr.988@gmail.com, arjunsr92@gmail.com, jrmarasalike@gmail.com and rpinto1942@gmail.com

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Abstract

Low frequency piezoelectric P(VDF-TrFE) micro-cantilever vibration sensors have been developed for the first time with a novel MEMS process. Design and simulation of micro-cantilevers were carried out using COMSOL Multiphysics based on finite element method. Frequencies and device dimensions were determined based on simulation results. The design was implemented on ⟨110⟩ Si wafer using a specially developed bulk micromachining process. Micro-cantilevers were fabricated with 2.5 μm thick P(VDF-TrFE) co-polymer film deposited by spin coating technique; electrodes for power output were formed by sequential thermal evaporation of Cr-Au thin films. The two critical process steps used for the suspension of P(VDF-TrFE) micro-cantilevers are: (1) bulk micromachining of silicon from the backside using anisotropic wet etchant TMAH to define the micro-cantilever suspension regions, and (2) CHF_3/O_2 based plasma etching of SiO_2 from backside for the final release of P(VDF-TrFE) micro-cantilevers. These devices were operated in longitudinal mode with Cr-Au interdigitated electrodes on P(VDF-TrFE) micro-cantilevers for power extraction. The experimental results obtained with laser Doppler vibrometer for micro-cantilevers with 1000 μm length, 300 μm width and 2.5 μm thickness showed resonant frequency 477.03 Hz and power output 187.4 pW for tip displacement 312.5 μm which are closely in agreement with the simulated values 453.65 Hz and 189 pW for tip displacement 310 μm, respectively. The volume power density of this P(VDF-TrFE) unimorph micro-cantilever is 249.92 nW mm^{-3}, which is found to be better compared with other polymer piezoelectric cantilevers.

Keywords: micro-electromechanical systems (MEMS), piezoelectric, P(VDF-TrFE) co-polymer, micro-cantilevers, vibration sensors, energy harvesters

(Some figures may appear in colour only in the online journal)

1. Introduction

Over the past several years, micro-electromechanical systems (MEMS) based devices have found applications in a variety of technologies which include inertial navigation systems [1], medical devices [2], wireless communication [3], pressure sensors [4], accelerometers [5] and others. For applications such as pressure sensors, accelerometers etc piezoelectric materials are essential. Among the most common piezoelectric materials, inorganic piezoelectric materials such as lead zirconium titanate (PZT) [6] and organic/polymer piezoelectric materials like Polyvinylidene fluoride (PVDF)

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Enhancement of power output in passive micro direct methanol fuel cells with optimized methanol concentration and trapezoidal flow channels

Arjun Sunil Rao[1*], K. R. Rashmi[2], D. V. Manjunatha[1], A. Jayarama[2#] and Richard Pinto[1]

[1] Department of Electronics and Communication Engineering, Alva's Institute of Engineering and Technology, Moodbidri, D. K., Karnataka, India.
[2] Department of Physics, Alva's Institute of Engineering and Technology, Moodbidri, D. K., Karnataka, India.

*E-mail: arjunsr92@gmail.com
#E-mail: jrmarasalike@gmail.com

Abstract

This work presents design, fabrication and optimization of methanol concentration and flow channel cross-sectional geometry for enhanced power output in passive micro direct methanol fuel cells. Passive micro direct methanol fuel cells are fabricated with flow channels in silicon having both rectangular and trapezoidal cross-sectional geometry for flow of methanol at anode and air at cathode using MEMS fabrication technique. The experiments are conducted at 25°C by feeding methanol with flow rate 25 µL/min and supply of air at cathode by air-breathing method. Results show a peak in open circuit voltage and power density at 7M methanol concentration for passive micro direct methanol fuel cells having both rectangular and trapezoidal cross-sectional geometry. A study of influence of silicon flow channel cross-sectional geometry on passive micro direct methanol fuel cell performance shows for the first time that the flow channels with trapezoidal cross-section enhance the power density (6.64 mW/cm^2) nearly by a factor of two compared to that of flow channels with rectangular cross-section (3.9 mW/cm^2) at 7M methanol concentration. We believe that though our results of significant enhancement of power density with trapezoidal fuel flow channels are obtained with micro-direct methanol fuel cells as a platform, they should be applicable to other proton exchange membrane fuel cells also with ethanol or humidified hydrogen as fuel.

Keywords: Passive micro-direct methanol fuel cell, gas diffusion layer, trapezoidal flow channels, methanol concentration.

1. Introduction

Passive micro-direct methanol fuel cells (µ-DMFCs) have evolved over the last few years because of numerous advantages, such as high power density, reliability and high fuel conversion efficiency which could lead to many applications [1-3]. There is considerable body of work carried out to enhance the power density and fuel conversion efficiency over the last decade in the field of µ-DMFCs [4-8]. While the efficiency and power density depend on thickness and equivalent weight of proton exchange membrane (PEM), both power density and fuel conversion also depend upon methanol concentration, flow channel geometry and operating temperature [9-11].

One of the most important parameters which limits the performance of µ-DMFCs is fuel crossover from the anode side to the cathode side through PEM (such as nafion) [12] and also the formation of CO_2 bubbles at the anode [13]. Crossover is a phenomenon of methanol diffusion through PEM and it is found to be dependent on methanol

Significant impact of Pd nanoparticle and CdS nanolayer of Pd@CdS@ZnO core-shell nanorods on enhancing catalytic, photoelectrochemical and photocurrent generation activity

Ji-Min Yu, Shambo Roy Chowdhury[2], Tae Il Lee[1*], Mrinmoy Misra[1*]

[1]Department of Bio Nano Technology, Gachon University, Seong-nam, Gyeonggi, 13120, Korea

[2]School of Automobile, Mechatronics, Mechanical, Manipal University Jaipur, India

Email id: mrinmoymishra@gmail.com, t2.lee77@gachon.ac.kr

Abstract

Pd@CdS@ZnO core-shell nanorods (NRs) have been prepared by using novel an easy chemical synthesis process. The superior catalytic activity of Pd@CdS@ZnO nanorods is attributable to the effective separation of electrons-hole pairs. The excitation-wavelength-dependent catalytic performance of Pd@CdS@ZnO NRs showed significant enhancement at the wavelengths analogous to the CdS layer. The recyclability results revealed a strong ability for the degradation of toxic organic pollutants with favorable reusable photocatalytic efficiency. Electrochemical impedance and photocurrent detection analysis further confirmed a reduced in the charge transfer resistance of Pd@CdS@ZnO NRs owing to embedded Pd NPs and coating of a CdS layer on ZnO NRs.

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Synergetic impact of surface plasmon hot electron and CuS nanolayer of CuS/Au/ZnO core-shell nanorods for the degradation of toxic pollutant

Jimin Yu, Tae Il Lee*, Mrinmoy Misra*

Department of BioNano Technology, Gachon University, Seong-nam Si, Gyeonggi Do, 13120, Republic of Korea

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ABSTRACT

CuS/Au/ZnO core-sell nanorods (NRs) have been synthesized by a novel and facile chemical method in an aqueous medium. The CuS/Au/ZnO NRs showed higher catalytic activity as compared to the ZnO NRs, Au/ZnO NRs, and CuS/ZnO NRs. The wavelength-dependent photocatalytic activity of the CuS/Au/ZnO NRs confirmed that the Au NPs act as the surface plasmon generated photocatalytic activity boosters and that CuS performs as a co-catalyst. The photocurrent generation and photo-electrochemical study further exhibited higher photocurrent generation and reduction of charge transfer resistance due to the synergistic impact of the Au NPs and CuS coating on the ZnO NRs.

Introduction

Environmental purification by effective utilization of solar energy through semiconductor photocatalytic nanomaterials to degrade toxic organic pollutants could facilitate global sustainability. Under ultraviolet (UV) irradiation, among the different efficient photocatalyst nanomaterials, zinc oxide (ZnO) is most commonly used for air and water purification, as it has many advantages including availability, lack of toxicity, great efficiency, photochemical stability, and robustness [1–5]. However, its visible blindness and high level of electron-hole pair recombination limit its usefulness as an efficient photocatalyst under solar light irradiation [6]. Therefore, improving the poor ability of ZnO to absorb visible light and to separate excitons is essential for ZnO to be a powerful photocatalyst.

Recently, to improve the visible photocatalytic activity of ZnO, the incorporation of metal nanoparticles (NPs), such as gold (Au) or silver (Ag), onto the ZnO surface has been reported. Hot electrons are generated by localized surface plasmon resonance (SPR) and transferred to the conduction band (CB) of ZnO over the Schottky barrier with the metal NPs [7–11]. This energy barrier can considerably suppress the charge recombination between the electrons present in ZnO and the holes in metal NPs, and can increase the probability for successive chemical reactions and thereby affect the performance of the photocatalyst [12,13]. Additionally, to further enhance photocatalytic efficiency, ZnO one-dimensional nanostructures such as nanorods, nanotubes, nanobelts, and nanowires have shown some inherent advantages, such as a fast collection of photogenerated charge carriers [14,15]. ZnO NRs is a wide band gap semiconductor material with unique optical, electronic, chemical, and physical properties. The one-dimensional (1D) structure of these materials confers some advantages, such as large aspect ratio, unidirectional electron mobility, and lower charge recombination rates.

Ultimately, to use all of the solar energy incident on the earth, ZnO can be incorporated with a visible light-active semiconductor material with a narrow band gap to absorb visible light and produce electron-hole pairs; the junction between ZnO and the semiconductor can efficiently separate the electron-hole pair for use in the catalytic chemical reaction [16–18]. There have been many reports about visible light-active photocatalysts, such as Cu_2O, CuS, PbS, CdS, CdTe, and CdSe, which can act as sensitizers with high absorption coefficients, broad absorption ranges, and different morphologies to modify the band gaps of the materials [19–25]. Sensitizers using elements like cadmium and lead are not suitable for practical application because of their toxicity. Thus, it is desirable to use a sensitizer that consists of nontoxic elements. Specifically, copper sulfide (CuS), which is a p-type semiconductor material with a narrow band gap of 2.2 eV and wide visible light absorption, has been noticed because of its chemical stability and excellent photocatalytic performance [26–28]. The most important feature of an incorporated visible light-absorbing nanomaterial is a core-shell shape that can assist the motion of the electrons or holes from the core to the shell, or vice versa, thereby leading to

* Corresponding authors.
E-mail addresses: t2.lee77@gmail.com (T.I. Lee), mrinmoymishra@gmail.com (M. Misra).

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Arjun Sunil Rao[1*], K. R. Rashmi[2], D. V. Manjunatha[1], A. Jayarama[2#] and Richard Pinto[1]

[1] Department of Electronics and Communication Engineering, Alva's Institute of Engineering and Technology, Moodbidri, D. K., Karnataka, India.
[2] Department of Physics, Alva's Institute of Engineering and Technology, Moodbidri, D. K., Karnataka, India.

[*]E-mail: arjunsr92@gmail.com ·
[#]E-mail: jrmarasalike@gmail.com

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