Passivation of surface states on hematite photoelectrode by ALD grown TiO2 for efficient solar water splitting

General information
State: Published
Organisations: Photonics, Tampere Univ Technol, Tampere University of Technology
Authors: Ali-Löytty, H., Valden, M., Palmolahti, L.
Publication date: 4 Dec 2017
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Event: Paper presented at Joint Annual Meeting of Finnish Synchrotron Radiation User Organisation (FSRUO) and Finnish Structural Biology Network (FinnBox), Turku, Finland.
Research output: Scientific › Paper, poster or abstract

Photo-electrochemical and spectroscopic investigation of ALD grown TiO2: Charge transfer characterization and effect of post annealing at different temperature

Inspired by the photo-electrochemical water oxidation system reported by Fujishima and Honda1, recent work has focused on functionalizing photoactive TiO2 thin films on silicon (Si) semiconductor. Targeting to design an efficient photo-electrochemical device for solar fuel production, finding suitable protection layer material for semiconductors like Si, has recently gained significant attention.

In this work, TiO2 thin films were deposited on highly doped Si substrate by atomic layer deposition (ALD) technique using tetrakis-dimethylamido titanium (TDMAT) and water as a precursors. In order to understand the influence of ALD parameters on TiO2 film performance in photo-electrochemical cell, ALD growth temperature was varied from 150 °C to 225 °C and film thickness from 20 nm to 50 nm. Further efforts were made to analyze the effect of post-annealing treatment in air on ALD films and its influence on photo-electrochemical water oxidation reaction.

The highest applied bias photon-to-current efficiency for Solar Water Splitting (SWS) was obtained in 30 nm ALD TiO2 film grown at 200 °C after post annealing at 475 °C. Annealing at higher temperatures decreased the photo-activity substantially. X-ray photoelectron spectroscopy analysis of TiO2 (2 nm)/Si samples after annealing in air revealed the onset of interfacial SiO2 formation at 450 °C. SiO2 at the TiO2/Si interface act as a charge transfer barrier with detrimental consequence on SWS on TiO2/Si photo-anode.

Broadband Anti-reflective Coatings for Multi-junction Solar Cells

General information
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Organisations: Facilities and Infrastructure, Photonics, Research group: ORC
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ASJC Scopus subject areas: Atomic and Molecular Physics, and Optics
Keywords: anti-reflective coating, thin films, multi-junction solar cell, material characterization
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Bibliographical note
Poster and an abstract for Optics and Photonics days 2017.
Research output: Scientific › Paper, poster or abstract
31% European InGaP/GaAs/InGaNAS Solar Cells For Space Application
We report a triple junction InGaP/GaAs/InGaNAS solar cell with efficiency of ~31% at AM0, 25 °C fabricated using a combined molecular beam epitaxy (MBE) and metal-organic chemical vapour deposition (MOCVD) processes. The prototype cells comprise of InGaNAS (Indium Gallium Nitride Arsenide) bottom junction grown on a GaAs (Gallium Arsenide) substrate by MBE and middle and top junctions deposited by MOCVD. Repeatable cell characteristics and uniform efficiency pattern over 4-inch wafers were obtained. Combining the advantages offered by MBE and MOCVD opens a new perspective for fabrication of high-efficiency space tandem solar cells with three or more junctions. Results of radiation resistance of the sub-cells are also presented and critically evaluated to achieve high efficiency in EOL conditions.

Composition and Bandgap determination of MBE-grown GaInNASb

Novel Concepts for High-efficiency lightweight space solar cells
One of the key issues in the design and development of a satellite Photovoltaic Assembly (PVA) is the trade-off to be made between the available volume located to the PVA, its mass and the total amount of power that the solar panels have to guarantee to the spacecraft. The development of high-efficiency, flexible, lightweight solar cells is therefore instrumental to the design of future satellites providing enhanced missions and services. Based on the consolidated development of GaAs-based single junction and lattice matched triple-junction solar cells, several research efforts are being pursued worldwide to further increase the efficiency and reduce mass. Promising approaches include thin-film technologies such as Inverted Metamorphic and Epitaxial Lift-Off (ELO), and the use of nanostructures or highly mismatched alloys grown by MBE. We propose here an alternative path towards the development of lightweight GaAs-based solar cells with the potential to exceed the Shockley-Queisser (SQ) limit of single junction cells. Our approach is based on the synergistic combination of thin-film design, quantum dots (QDs) absorption, and photonic nanostructures. Challenges and opportunities offered by the use of QDs are discussed. A cost-effective and scalable fabrication process including ELO
technology and nanoimprint lithography is outlined. Finally, a proof-of-concept design, based on rigorous electromagnetic
and physics-based simulations, is presented. Efficiency higher than 30% and weight reduction close to 90% - owing to the
substrate removal - makes the proposed device to rank record power-to-weight ratio, with the potential to become a cost-
effective, attractive option for next generation space solar cells.

General information
State: Published
Ministry of Education publication type: A4 Article in a conference publication
Organisations: Photonics, Research group: ORC, Politecnico di Torino, Radboud University, tf2 devices, Thales Alenia
Space, University College London
Authors: Cappelluti, F., Ghione, G., Gioannini, M., Bauhuis, G., Mulder, P., Schermer, J., Cimino, M., Gervasio, G.,
Publication date: 2017

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Publisher: ESA Publications Division
Article number: 03007

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Name: E3S Web of Conferences
Volume: 16
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DOIs:
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Links:
http://urn.fi/URN:NBN:fi:tty-201706201607
Research output: Scientific - peer-review › Conference contribution

Performance of Dilute Nitride Triple Junction Space Solar Cell Grown by MBE
Dilute nitride arsenide antimonide compounds offer widely tailorable band-gaps, ranging from 0.8 eV to 1.4 eV, for the
development of lattice-matched multijunction solar cells with three or more junctions. Here we report on the performance
of GaInP/GaAs/GaInNAsSb solar cell grown by molecular beam epitaxy. An efficiency of 27% under AM0 conditions is
demonstrated. In addition, the cell was measured at different temperatures. The short circuit current density exhibited a
temperature coefficient of 0.006 mA/cm2/°C while the corresponding slope for the open circuit voltage was −6.8 mV/°C.
Further efficiency improvement, up to 32%, is projected by better current balancing and structural optimization.

General information
State: Published
Ministry of Education publication type: A4 Article in a conference publication
Organisations: Photonics, Research group: ORC
Authors: Aho, A., Isoaho, R., Tukiainen, A., Polojärvi, V., Raappana, M., Aho, T., Guina, M.
Publication date: 2017

Host publication information
Title of host publication: 11th European Space Power Conference, 3-7 October 2016 Thessaloniki, Greece
Publisher: EDP Sciences
Article number: 03008

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Name: E3S Web of Conferences
Volume: 16
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Research output: Scientific - peer-review › Conference contribution
Enhancement of Photocurrent in GaInNAs Solar Cells using Ag/Cu Double-Layer Back Reflector

General information
State: E-pub ahead of print
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications, Research group: Nanophotonics
Authors: Aho, T., Aho, A., Tukiainen, A., Polojarvi, V., Salminen, T., Raappana, M., Guina, M.
Publication date: 22 Dec 2016
Peer-reviewed: Yes

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Scopus rating (2015): SJR 1.085 SNIP 0.983 CiteScore 2.47
Scopus rating (2014): SJR 1.799 SNIP 1.462 CiteScore 3.25
Scopus rating (2013): SJR 2.149 SNIP 1.652 CiteScore 3.77
Scopus rating (2012): SJR 2.554 SNIP 1.754 CiteScore 3.76
Scopus rating (2011): SJR 2.805 SNIP 1.94 CiteScore 4.04
Scopus rating (2010): SJR 2.926 SNIP 1.789
Scopus rating (2009): SJR 2.857 SNIP 1.848
Scopus rating (2008): SJR 2.934 SNIP 1.83
Scopus rating (2007): SJR 3.039 SNIP 1.913
Scopus rating (2006): SJR 3.457 SNIP 2.288
Scopus rating (2005): SJR 3.709 SNIP 2.382
Scopus rating (2004): SJR 3.904 SNIP 2.38
Scopus rating (2003): SJR 3.765 SNIP 2.27
Scopus rating (2002): SJR 3.917 SNIP 2.365
Scopus rating (2001): SJR 4.111 SNIP 2.212
Scopus rating (2000): SJR 4.277 SNIP 2.013
Scopus rating (1999): SJR 4.35 SNIP 2.11
Original language: English
Electronic versions:
Enhancement of photocurrent in GaInNAs solar cells using AgCu double-layer back reflector

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Links:
http://urn.fi/URN:NBN:fi:tty-201612234915
Research output: Scientific - peer-review › Article

Thermal Modification of ALD Grown Titanium Oxide Ultra Thin Film for Photoanode Applications

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Surface Science
Authors: Hannula, M. K., Lahtonen, K. T., Isotalo, T. J., Saari, J. S., Valden, M. O.
Publication date: 15 Dec 2016
Peer-reviewed: Unknown
Event: Paper presented at Symposium on Future Prospects for Photonics, Tampere, Finland.
ASJC Scopus subject areas: Renewable Energy, Sustainability and the Environment, Surfaces, Coatings and Films, Surfaces and Interfaces, Atomic and Molecular Physics, and Optics
Keywords: Titanium dioxide, titanium silicide, Atomic layer deposition (ALD), photoemission electron microscopy, PEEM, hydrogen energy
Research output: Scientific › Paper, poster or abstract
Fabrication of topographically microstructured titanium silicide interface for advanced photonic applications

We present a widely scalable, high temperature post-growth annealing method for converting ultra-thin films of TiO2 grown by atomic layer deposition to topographically microstructured titanium silicide (TiSi). The photoemission electron microscopy results reveal that the transformation from TiO2 to TiSi at 950 °C proceeds via island formation. Inside the islands, TiO2 reduction and Si diffusion play important roles in the formation of the highly topographically microstructured TiSi interface with laterally nonuniform barrier height contact. This is advantageous for efficient charge transfer in Si-based heterostructures for photovoltaic and photoelectrochemical applications.

General Information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Surface Science, Research group: Nanophotonics, MAX IV Laboratory, Lund University
Number of pages: 6
Pages: 76-81
Publication date: Jul 2016
Peer-reviewed: Yes

Publication Information
Journal: Scripta Materialia
Volume: 119
ISSN (Print): 1359-6462
Ratings:
Scopus rating (2016): SJR 1.901 SNIP 1.696 CiteScore 3.71
Scopus rating (2015): SJR 2.3 SNIP 1.876 CiteScore 3.54
Scopus rating (2014): SJR 2.744 SNIP 2.124 CiteScore 3.55
Optically Enhanced GaInNAs Solar Cell

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Aho, T. A., Aho, A., Tukiainen, A., Polojarvi, V., Raappana, M., Guina, M.
Publication date: 20 Jun 2016
Peer-reviewed: Unknown
Research output: Scientific › Paper, poster or abstract

Ambient-Pressure XPS Study of a Ni-Fe Electrocatalyst for the Oxygen Evolution Reaction
Chemical analysis of solid-liquid interfaces under electrochemical conditions has recently become feasible due to the development of new synchrotron radiation techniques. Here we report the use of "tender" X-ray ambient-pressure X-ray photoelectron spectroscopy (APXPS) to characterize a thin film of Ni-Fe oxyhydroxide electrodeposited on Au as the working electrode at different applied potentials in 0.1 M KOH as the electrolyte. Our results show that the as-prepared 7 nm thick Ni-Fe (50% Fe) film contains Fe and Ni in both their metallic as well as oxidized states, and undergoes further oxidation when the sample is subjected to electrochemical oxidation-reduction cycles. Metallic Fe is oxidized to Fe$^{3+}$ and metallic Ni to Ni$^{2+/3+}$. This work shows that it is possible to monitor the chemical nature of the Ni-Fe catalyst as a function of potential when the corresponding current densities are small. This allows for operando measurements just above the onset of OER; however, current densities as they are desired in photoelectrochemical devices ($\sim$1-10 mA cm$^{-2}$) could not be achieved in this work, due to ohmic losses in the thin electrolyte film. We use a two-dimensional model to describe the spatial distribution of the electrochemical potential, current density, and pH as a function of the position above the electrolyte meniscus, to provide guidance toward enabling the acquisition of operando APXPS at high current density. The shifts in binding energy of water with applied potential predicted by the model are in good agreement with the experimental values.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Surface Science, SUNCAT Center for Interface Science and Catalysis, SLAC National Accelerator Laboratory, Department of Chemical and Biomolecular Engineering, Berkeley, Materials Sciences Division, Lawrence Berkeley National Laboratory, Materials and Corrosion Engineering, Exponent, Inc., Polymer Science and Materials Chemistry
Number of pages: 7
Color Bricks: Building Highly Organized and Strongly Absorbing Multicomponent Arrays of Terpyridyl Perylenes on Metal Oxide Surfaces

Terpyridine-substituted perylenes containing cyclic anhydrides in the peri position were synthesized. The anhydride group served as an anchor for assembly of the terpyridyl-crowned chromophores as monomolecular layers on metal oxide surfaces. Further coordination with Zn2+ ions allowed for layer-by-layer formation of supramolecular assemblies of perylene imides on the solid substrates. With properly selected anchor and linker molecules it was possible to build high quality structures of greater than ten successive layers by a simple and straightforward procedure. The prepared films were stable and had a broad spectral coverage and high absorbance. To demonstrate their potential use, the synthesized dyes were employed in solid-state dye-sensitized solar cells, and electron injection from the perylene antennas to titanium dioxide was observed.
Scopus rating (2015): SJR 2.416 SNIP 1.184 CiteScore 4.99
Scopus rating (2014): SJR 2.487 SNIP 1.219 CiteScore 5.51
Scopus rating (2013): SJR 2.604 SNIP 1.239 CiteScore 5.68
Scopus rating (2012): SJR 2.884 SNIP 1.294 CiteScore 5.55
Scopus rating (2011): SJR 2.726 SNIP 1.336 CiteScore 5.46
Scopus rating (2010): SJR 2.527 SNIP 1.292
Scopus rating (2009): SJR 2.499 SNIP 1.365
Scopus rating (2008): SJR 2.887 SNIP 1.407
Scopus rating (2007): SJR 3.233 SNIP 1.532
Scopus rating (2006): SJR 2.911 SNIP 1.505
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Scopus rating (2004): SJR 2.32 SNIP 1.472
Scopus rating (2003): SJR 2.156 SNIP 1.45
Scopus rating (2002): SJR 2.554 SNIP 1.472
Scopus rating (2001): SJR 2.834 SNIP 1.612
Scopus rating (2000): SJR 2.956 SNIP 1.652
Scopus rating (1999): SJR 3.013 SNIP 1.73
Original language: English
DOIs:
10.1002/chem.201503738

Bibliographical note
ORG=keb,0.5
ORG=orc,0.5
Research output: Scientific - peer-review › Article

Dilute Nitride Four-Junction Solar Cell

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications,
Optoelectronics Research Centre, Tampere University of Technology
Publication date: 2016
Peer-reviewed: Unknown
Event:
Research output: Scientific › Paper, poster or abstract

Dilute Nitride Multijunction Cells: Recent progress and Future Outlook

General information
State: Published
Organisations: Photonics
Publication date: 2016
Peer-reviewed: Unknown
Event: Paper presented at Optics and Photonics days, Tampere, Finland.
Research output: Scientific › Paper, poster or abstract

Dilute nitride solar cells fabricated by combined MBE-MOCVD epitaxy

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Publication date: 2016
Peer-reviewed: Unknown
Event: Paper presented at 12th International Conference on Concentrator Photovoltaics (CPV-12), Freiburg, Germany.
Electronic versions:
Electrical isolation of dilute nitride solar cells by wet etching

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Publication date: 2016
Peer-reviewed: Unknown
Event: Paper presented at Optics and Photonics days, Tampere, Finland.
Research output: Scientific › Paper, poster or abstract

Electrical isolation of high-efficiency dilute nitride multijunction solar cells

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Raappana, M., Polojärvi, V., Aho, T., Aho, A., Tukiainen, A., Hytönen, L., Isoaho, R., Guina, M.
Publication date: 2016

Host publication information
Title of host publication: Physics days 2016 : Proceedings of the 50th annual conference of the Finnish Physical Society
Place of publication: Oulu
Publisher: Finnish Physical Society

Bibliographical note
INT=orc:"Hytönen, Lauri"
Research output: Scientific › Conference contribution

HCl-based wet etching of III-V dilute nitride materials for multijunction solar cells

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Publication date: 2016
Peer-reviewed: Unknown
Research output: Scientific › Paper, poster or abstract

High efficiency dilute nitride solar cells: Simulations meet experiments
Parameter extraction procedure and simulation of dilute nitride solar cells are reported. Using PC1D simulation and fitting to experimental current-voltage and external quantum efficiency data, we retrieve the phenomenological material parameters for GaInNAs solar cells. Based on these, we have constructed a model that can explain the changes in short circuit current and open circuit voltage of n-i-p solar cells subjected to rapid thermal annealing. The model reveals that non-annealed MBE-grown GaInNAs material has an n-type doping that evolves to p-type upon rapid thermal annealing. The change of doping type and the shift of the physical location of the pn-junction were confirmed by Kelvin-probe force microscopy. The PC1D modelling was found to work well also for GaInNAs p-i-n solar cells with opposite polarity. It was also found that the GaInNAs lower doping levels in p-i-n solar cells grown at lowered As/III flux ratios were associated with increased carrier lifetimes.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Tukiainen, A., Aho, A., Polojärvi, V., Ahorinta, R., Guina, M.
Number of pages: 20
Pages: 113-132
Publication date: 2016
High-efficiency III-V solar cells: From drawing board to real devices

The record solar cell conversion efficiency of 46% at concentrated sunlight has been demonstrated by direct bonding technique [1]. Regardless of the high efficiencies obtained using the direct wafer bonding technique, the conventional monolithic approach used in commercial solar cell production has several benefits, including production technology and cost-related factors. And yet, there is a high unused potential, particularly in new materials that can be grown lattice-matched onto GaAs or Ge substrates. For example, by utilizing dilute nitride materials in mult junction solar cell structures with more than three junctions and by carefully optimizing structural elements and manufacturing technology, efficiencies exceeding 50% is a realistic target [2]. Here we review our theoretical and experimental work carried out on development of various parts of high-efficiency multijunction solar cells based on GaInNAsSb-based materials, i.e., dilute nitrides. First of all, we have developed a molecular beam epitaxy process for GaInNAsSb sub-junction with very high external quantum efficiency exceeding 90%. This building block is essential for achieving high conversion efficiency for GaInP/GaAs/GaInNAsSb triple-junction solar cells. Secondly, the use of a variety of electro-optical simulation tools such as Crosslight APSYS, Silvaco TCAD, PC1D, Essential MacLeod and semi-empirical analytical models combined with experimental work on numerous test samples have helped in fabricating ultra-low specific resistivity tunnel junctions and high-quality sub-junctions based on conventional III-V materials such as GaInP and GaAs to be integrated with the dilute nitride sub-junction. Thirdly, we have also extracted important material specific physical parameters such as carrier lifetimes, mobilities and concentrations for dilute nitrides by matching the simulations to experimental solar cell device characteristics [3]. The extracted parameters are used for refining the simulation models which provide deeper understanding of the device physics. The work done so far has led to a rapid increase in conversion efficiency of our GaInP/GaAs/GaInNAsSb triple-junction solar cells – at a pace of ~5% points/year since 2012. High-efficiency solar cells with efficiencies of 29% and 31% at one sun (AM0 and AM1.5G, respectively) and 36–39% under concentrated sunlight (at ~70 suns) have already been demonstrated [4,5]. Additionally, the effects of various optical and structural design elements related to fabrication of real III-V multijunction solar cells will be critically reviewed. Especially, we will concentrate on the pros and cons of backside reflector structure architectures – including various planar reflector types and Lambertian scatterers – and nanostructured antireflection coatings [6] which are currently widely employed for solar cell photon management. The consequences of adding such elements to the fabrication process and impact on improving the conversion efficiency towards >50% efficiency are assessed.
Increasing the quantum efficiency of GaInNAs solar cells by advanced optical design

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Aho, T. A., Aho, A., Tukiainen, A., Polojärvi, V., Raappana, M., Guina, M.
Publication date: 2016
Peer-reviewed: Unknown
Event: Paper presented at Optics and Photonics days, Tampere, Finland.
Research output: Scientific › Paper, poster or abstract

Optimizing iron alloy catalyst materials for photoelectrochemical water splitting: Passivation of FeCr alloy surface by water vapour using near-ambient-pressure photoelectron spectroscopy

General information
State: Published
Ministry of Education publication type: D4 Published development or research report or study
Organisations: Optoelectronics Research Centre, Research group: Surface Science, MAX IV Laboratory, Lund University
Authors: Lahtonen, K., Hannula, M., Ali-Löytty, H., Hirsimäki, M., Urpelainen, S., Valden, M.
Number of pages: 2
Publication date: 2016

Publication information
Place of publication: Lund, Sweden
Publisher: Lund University, MAX IV Laboratory
Original language: English
Keywords: Synchrotron, Steel, photoelectrochemical water splitting, Passivation, near-ambient-pressure photoelectron spectroscopy, APXPS
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https://www.maxlab.lu.se/cmis/display?id=workspace%3A%2F%2FSpacesStore%2Fa92d6a04-214f-4072-9777-93aed805058
Links:
https://www.maxlab.lu.se/node/2032 (Reports 2015 - Syncrotron Radiation)
Research output: Professional › Commissioned report

Pohjoismaiden energiapoliittikka 2030: Hiilineutraalimpaan energiajärjestelmään osin yhdessä, osin eri polkuja pitkin

General information
State: Published
Ministry of Education publication type: D4 Published development or research report or study
Organisations: Department of Civil Engineering, Department of Electrical Engineering, Department of Chemistry and Bioengineering, Department of Physics, Research group: Construction Processes, University of Tampere, VTT
Number of pages: 23
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Publication information

Publication series
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Keywords: Energy policy, Energy system, Carbon footprint
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https://tt.eduuni.fi/sites/EL-TRAN/Julkiset%20tiedostot/Pami%20Aalto%20et%20al,%20Pohjoismainen%20energiapoliittikka%202030%20--%20hiilineutraalimpaan%20energiaj%C3%A4rjestelm%C3%A4n%20kehityksen%20arviointi.pdf
Research output: Professional › Discussion paper
Transformation of ALD grown TiO2 film to topographically microstructured titanium silicide for photonics applications

General information
State: Published
Ministry of Education publication type: D4 Published development or research report or study
Organisations: Optoelectronics Research Centre, Research group: Surface Science, Research group: Nanophotonics
Number of pages: 2
Publication date: 2016

Publication information
Place of publication: Lund
Publisher: Lund University, MAX IV Laboratory
Original language: English
Keywords: titanium silicide, Synchrotron, photoemission electron microscopy
Links:
https://www.maxlab.lu.se/cmis/display?id=workspace%3A%2F%2FSpacesStore%2F80e2da54-8373-4d0c-a4af-8b53b81b0ca3
Links:
https://www.maxlab.lu.se/node/2032#I311-PEEM_ (Reports 2015 - Syncrotron Radiation)
Research output: Professional › Commissioned report

X-ray photoelectron spectroscopy of electrochemical interfaces for solar fuel production

General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Surface Science
Authors: Ali-Löytty, H., Valden, M.
Number of pages: 1
Pages: 114
Publication date: 2016
Peer-reviewed: Unknown
Event: Paper presented at Physics days 2016, Oulu, Finland.
Research output: Scientific › Paper, poster or abstract

Single-source multibattery solar charger: Case study and implementation issues
In this paper, design process and functionality of a portable single-panel dual-battery solar charger prototype are presented, achieving energy density of 571 Wh kg⁻¹ during a typical 3-day infantry mission. The device may instantaneously charge up to two Li-ion MR-2791 batteries, supporting plug-and-play operation. The system consists of a lightweight custom solar panel, based on 20% efficient monocrystalline photovoltaics, and an intelligent power processing module. The panel contains eight transparent polymer-encapsulated and camouflaged series-connected six solar cell packs with antiparallel diodes, allowing partial shading operation. The power processing module consists of two synchronous current-mode-controlled buck converters, digital signal processor, and a microcontroller, supporting both maximum power point tracking of the solar panel with partial shading detection and multimode charging of Li-ion packs while instantaneously communicating with the batteries. Power management algorithmic design is presented, based on ensuring system stability while supporting the required operation modes. System implementation stages and underlying issues are thoroughly discussed, and utilized hardware components are presented in detail. Experimental results of system testing under real outdoor conditions are presented to demonstrate the device functionality and energy yield capabilities.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Department of Electrical Engineering, Research area: Power engineering, Smart Energy Systems (SES), Hybrid Energy Sources Laboratory
Authors: Gadelovits, S., Sitbon, M., Suntio, T., Kuperman, A.
Number of pages: 13
Pages: 1916-1928
Publication date: 25 Nov 2015
Peer-reviewed: Yes

Publication information
Journal: Progress in Photovoltaics: Research and Applications
Volume: 23
Dilute Nitride Multijunction Solar Cells Grown by Molecular Beam Epitaxy

Solar cells generate green energy directly from sunlight. The energy conversion efficiency of solar cells depends strongly on materials used as absorbers and the cell architecture. Currently, the best solar cells convert sunlight energy to electricity with an efficiency of up to 46%. This thesis focuses on the development of dilute-nitride materials and related solar cells, which are one of the most promising approaches for achieving even higher efficiencies. Applications for these cells include concentrated photovoltaic and space power systems. In particular, the thesis focuses on developing solar cell materials based on GaInNAsSb, which can provide efficient light absorption and energy conversion for a photon energy range of 0.8 eV-1 eV, typically challenging for conventional III-V semiconductors. The GaInNAsSb semiconductor materials were synthesized by molecular beam epitaxy.

The experimental work of this thesis explored the dependence of the fabrication parameters on the GaInNAsSb material and solar cell properties. It was observed that for many of the growth parameters even a slight change of the value can have a significant effect on the solar cell performance. A N incorporation model was developed to help the iteration process for growth parameter tuning. For optimized growth conditions, nearly ideal current generation for GaInNAsSb based material was achieved. Based on external quantum efficiency measurements it was possible to collect up to ~90% of the photons in the spectral range of the GaInNAsSb junction. In addition, an excellent fill factor of 0.7 and voltages in the range of 0.5 V for a 1 eV GaInNAsSb junction were measured.

Simulation based on a state-of-the-art GaInP/GaAs double junction cell, a commercial GaInP/GaAs/Ge triple junction cell and GaInNAsSb single junction cells studied in this thesis, revealed that a GaInP/GaAs/GaInNAsSb/Ge cell at the one sun concentration can have 1.7 percentage points higher efficiency than GaInP/GaAs/GaInNAsSb cell. In addition, the estimated efficiency of a four junction cell at 300 suns would be 3.6 percentage points higher than for a GaInP/GaAs/GaInNAsSb cell. The optimized single junction GaInNAsSb cell was experimentally tested into a GaInP/GaAs/GaInNAsSb cell in this work. The one sun efficiency of the cell under AM1.5G spectral conditions was 31% and the efficiency of the cell at 70 suns concentration was 37-39%. The one sun result is 91% of the projected efficiency. The results under concentrated conditions are expected to be improved by optimizing of the cell top grid design, layer structure and interfaces. As future concepts are concerned, a nanopatterned moth eye antireflection coating was fabricated on top of the GaInP/GaAs/GaInNAsSb cell, which was then compared to a cell that had a traditional two layer TiO2/SiO2 coating. The moth eye nanostructure had a low average reflection of 2% in the spectral range of 400-1700 nm.
being less than half of the reflectance of the TiO2/SiO2 coating. For future work, the absorption loss for the nanostructure coating at wavelengths below 500 nm needs to be reduced.

**General information**
State: Published
Ministry of Education publication type: G5 Doctoral dissertation (article)
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Aho, A.
Number of pages: 80
Publication date: 14 Nov 2015

**Publication information**
Publisher: Tampere University of Technology
Original language: English

**Publication series**
Name: Tampere University of Technology. Publication
Publisher: Tampere University of Technology
Volume: 1343
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**Bibliographical note**
Awarding institution: Tampere University of Technology
Research output: Collection of articles › Doctoral Thesis

**Effects of thinning and heating for TiO2/AlInP junctions**
TiO2/AlInP junctions are used to construct the antireflection coatings for solar cells and to passivate III-V nanostructure surfaces. The thickness of AlInP epilayer affects light absorption and appropriate Al composition determining further the energy barrier for carriers. We report on reducing the AlInP thickness by dry etching down to 10 nm without introducing harmful defect states at TiO2/AlInP interface and AlInP/GaInP interface below, according to photoluminescence. Synchrotron-radiation photoelectron spectroscopy reveals that increased oxidation of phosphorus is not harmful to TiO2/AlInP and that post heating of the material enhances AlInP oxidation and group III element segregation resulting in decreased material homogeneity.

**General information**
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications, Frontier Photonics, Department of Physics and Astronomy, University of Turku, University of Turku
Number of pages: 4
Pages: 6-9
Publication date: 24 Aug 2015
Peer-reviewed: Yes

**Publication information**
Journal: Journal of Electron Spectroscopy and Related Phenomena
Volume: 205
ISSN (Print): 0368-2048
Ratings:
Scopus rating (2016): SJR 0.962 SNIP 0.837 CiteScore 1.72
Scopus rating (2015): SJR 0.813 SNIP 0.923 CiteScore 1.73
Scopus rating (2014): SJR 0.778 SNIP 0.815 CiteScore 1.48
Scopus rating (2013): SJR 0.91 SNIP 0.954 CiteScore 1.82
Scopus rating (2012): SJR 1.047 SNIP 0.954 CiteScore 1.72
Scopus rating (2011): SJR 1.06 SNIP 0.842 CiteScore 1.68
Scopus rating (2010): SJR 0.742 SNIP 0.658
Improved adaptive input voltage control of a solar array interfacing current mode controlled boost power stage

Nonlinear characteristics of photovoltaic generators were recently shown to significantly influence the dynamics of interfacing power stages. Moreover, since the dynamic resistance of photovoltaic generators is both operating point and environmental variables dependent, the combined dynamics exhibits these dependencies as well, burdening control challenge. Typically, linear time invariant input voltage loop controllers (e.g. Proportional-Integrative-Derivative) are utilized in photovoltaic applications, designed according to nominal operating conditions. Nevertheless, since actual dynamics is seldom nominal, closed loop performance of such systems varies as well. In this paper, adaptive control method is proposed, allowing to estimate photovoltaic generator resistance online and utilize it to modify the controller parameters such that closed loop performance remains nominal throughout the whole operation range. Unlike previously proposed method, utilizing double-grid-frequency component for estimation purposes and suffering from various drawbacks such as operation point dependence and applicability to single-phase grid connected systems only, the proposed method is based on harmonic current injection and is independent on operating point and system topology.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Department of Electrical Engineering, Research area: Power engineering, Smart Energy Systems (SES), Dept. of Electrical Engineering and Electronics, Ariel University
Authors: Sitbon, M., Schacham, S., Suntio, T., Kuperman, A.
Number of pages: 7
Pages: 369-375
Publication date: 1 Jul 2015
Peer-reviewed: Yes

Publication information
Journal: Energy Conversion and Management
Volume: 98
ISSN (Print): 0196-8904
Ratings:
Scopus rating (2016): SJR 2.287 SNIP 2.065 CiteScore 6.04
Scopus rating (2015): SJR 2.09 SNIP 2.092 CiteScore 5.24
Scopus rating (2014): SJR 1.854 SNIP 2.835 CiteScore 5.35
Scopus rating (2013): SJR 1.669 SNIP 2.558 CiteScore 4.49
Scopus rating (2012): SJR 1.732 SNIP 2.277 CiteScore 3.72
Scopus rating (2011): SJR 1.292 SNIP 1.846 CiteScore 3.03
Scopus rating (2010): SJR 1.372 SNIP 1.75
Scopus rating (2009): SJR 1.339 SNIP 1.797
Comprehensive dynamic analysis of photovoltaic generator interfacing DC-DC boost power stage

In transformer-less grid-connected renewable energy systems, interfacing of photovoltaic (PV) generators is typically implemented by means of DC-DC boost-power-stage converter, mainly because of its voltage-boosting capability. In order to track the maximum power point of a PV generator, input voltage of the converter is usually feedback controlled, forcing the converter to operate as a current-sourced rather than voltage-sourced converter. Nevertheless, PV generator interfacing power stage is commonly assumed to possess the same dynamic properties as corresponding voltage-sourced power stage. Investigations presented in this study reveal explicitly that the dynamics of PV generator interfacing DC-DC boost power stage resembles conventional buck power stage behaviour with duty-cycle independent resonance and additional right-half-plane zeros. In addition, the duty cycle has to be decreased for increasing the corresponding output variables (i.e. input voltage and output current). Extended experimental results are given to support the theoretical findings.
Matlab/Simulink modeling to study the effect of partially shaded condition on photovoltaic array's maximum power point

Dynamics of photovoltaic-generator-interfacing voltage-controlled buck power stage

This paper investigates the dynamic properties of the photovoltaic-generator-interfacing voltage-controlled buck power stage operating in both the maximum and limited power point tracking modes. The photovoltaic generator (PVG) is known to possess both current- and voltage-source properties with respect to its maximum power point. While voltage-fed operation is conventional, current-fed action is nontrivial and is thoroughly analyzed in this paper. The photovoltaic-generator-interfacing converter is formed by adding a capacitor at conventional voltage-fed converter input terminals, turning it into a current-fed power stage. During the maximum power point tracking phase, converter input voltage is regulated, possessing nontrivial dynamics. The situation is burdened further when output-voltage control should be alternatively realized to limit the voltage of the converter terminating the energy storage element. It is shown that both the
photovoltaic generator and the terminating energy storage greatly affect the combined system dynamics. Parallel as well as cascaded control arrangements are proposed to support dual-mode system operation. Extended experimental results are shown to enforce presented theory and reveal nontrivial dynamics-related issues.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Department of Electrical Engineering, Research area: Power engineering, Smart Energy Systems (SES), Hybrid Energy Sources RandD Laboratory, Ariel University, ABB Oy, Drives
Authors: Sitbon, M., Leppäaho, J., Suntio, T., Kuperman, A.
Number of pages: 8
Pages: 633-640
Publication date: 1 Mar 2015
Peer-reviewed: Yes

Publication information
Journal: IEEE Journal of Photovoltaics
Volume: 5
Issue number: 2
ISSN (Print): 2156-3381
Ratings:
Scopus rating (2016): CiteScore 4.14 SJR 1.512 SNIP 1.58
Scopus rating (2015): SJR 1.909 SNIP 1.966 CiteScore 4.42
Scopus rating (2014): SJR 1.212 SNIP 1.888 CiteScore 3.87
Scopus rating (2013): SJR 1.357 SNIP 3.532 CiteScore 3.84
Scopus rating (2012): SJR 0.863 SNIP 2.774 CiteScore 2.2
Original language: English
ASJC Scopus subject areas: Electrical and Electronic Engineering, Electronic, Optical and Magnetic Materials, Condensed Matter Physics
Keywords: Current-fed buck converter, dynamics, photovoltaic generator (PVG)
DOIs: 10.1109/JPHOTOV.2014.2379094
Source: Scopus
Source-ID: 84923933523
Research output: Scientific - peer-review › Article

III-N/Bu-V based high efficiency solar cells: recent developments ad future prospects
General information
State: Published
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Guina, M.
Publication date: 2015
Peer-reviewed: Unknown

Bibliographical note
xpresentation
"Invited talk"
Research output: Scientific › Paper, poster or abstract

MBE GROWN GaInNAsSb MULTIJUNCTION SOLAR CELLS: PATH TOWARDS 50% EFFICIENCY
General information
State: Published
Ministry of Education publication type: D3 Professional conference proceedings
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications
Authors: Aho, A. J., Polojärvi, V. V., Aho, T. A., Raappana, M. J. S., Tukiainen, A. K., Guina, M. D.
Publication date: 2015

Host publication information
Title of host publication: 18th European Molecular Beam Epitaxy Workshop. Canazei, Italy
ASJC Scopus subject areas: Energy(all)
Optical properties and thermionic emission in solar cells with InAs quantum dots embedded within GaNAs and GaInNAs

The optical properties of p-i-n solar cells comprised of InAs quantum dots embedded within GaNAs and GaInNAs quantum wells are reported. Strain compensating and mediating GaNAs and GaInNAs layers shift the photoluminescence emission as well as absorption edge of the quantum dots to longer wavelengths. GaNAs and GaInNAs quantum wells contribute also to extending the absorption edge. In addition, the use of GaNAs and GaInNAs layers enhances the thermal escape of electrons from QDs by introducing steps for electrons to the GaAs conduction band.

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Semiconductor Technology and Applications, Augmented Human Activities (AHA), Frontier Photonics, Faculty of Exact Sciences and Engineering, Hyperion University
Authors: Polojärvi, V., Pavelescu, E., Schramm, A., Tukiainen, A., Aho, A., Puustinen, J., Guina, M.
Number of pages: 4
Pages: 122-125
Publication date: 2015
Peer-reviewed: Yes
Early online date: 19 Jun 2015

Publication information
Journal: Scripta Materialia
Volume: 108
ISSN (Print): 1359-6462
Ratings:
Scopus rating (2016): SJR 1.901 SNIP 1.696 CiteScore 3.71
Scopus rating (2015): SJR 2.3 SNIP 1.876 CiteScore 3.54
Scopus rating (2014): SJR 2.744 SNIP 2.124 CiteScore 3.55
Scopus rating (2013): SJR 2.347 SNIP 1.975 CiteScore 3.19
Scopus rating (2012): SJR 2.309 SNIP 2.022 CiteScore 3.01
Scopus rating (2011): SJR 2.333 SNIP 2.108 CiteScore 3.21
Scopus rating (2010): SJR 2.445 SNIP 2.125
Scopus rating (2009): SJR 2.574 SNIP 2.02
Scopus rating (2008): SJR 2.634 SNIP 2.128
Scopus rating (2007): SJR 2.229 SNIP 2.174
Scopus rating (2006): SJR 2.1 SNIP 1.915
Scopus rating (2005): SJR 1.831 SNIP 1.915
Scopus rating (2004): SJR 1.464 SNIP 1.731
Scopus rating (2003): SJR 1.499 SNIP 1.709
Scopus rating (2002): SJR 1.509 SNIP 1.345
Scopus rating (2001): SJR 1.301 SNIP 1.361
Scopus rating (2000): SJR 1.268 SNIP 1.123
Scopus rating (1999): SJR 1.53 SNIP 1.162
Original language: English
ASJC Scopus subject areas: Materials Science(all), Condensed Matter Physics
Keywords: Quantum dot, Quantum well, Solar cell, Strain engineering, Thermal escape
DOI:
10.1016/j.scriptamat.2015.06.033

Bibliographical note
EXT="Pavelescu, Emil-Mihai"
Source: Scopus
Source-ID: 84936804579
Research output: Scientific - peer-review › Article
Temperature coefficients for GaInP/GaAs/GaInNAsSb solar cells

We report the temperature coefficients for MBE-grown GaInP/GaAs/GaInNAsSb multijunction solar cells and the corresponding single junction sub-cells. Temperature-dependent current-voltage measurements were carried out using a solar simulator equipped with a 1000W Xenon lamp and a three-band AM1.5D simulator. The triple-junction cell exhibited an efficiency of 31% at AM1.5G illumination and a conversion efficiency of 37-39% at 70x real sun concentration. The external quantum efficiency was also measured at different temperatures. The temperature coefficients up to 80°C, for the open circuit voltage, the short circuit current density, and the conversion efficiency were determined to be -7.5mV/°C, 0.040mA/cm²/°C, and -0.09%/°C, respectively.
Deep levels in 1 eV bandgap dilute nitride antimonide solar cells

**General information**

State: Published  
Ministry of Education publication type: A4 Article in a conference publication  
Organisations: Optoelectronics Research Centre  
Authors: Polojärvi, V., Tukiainen, A., Aho, A., Raappana, M., Aho, T., Schramm, A., Guina, M.  
Number of pages: 3  
Pages: 1-3  
Publication date: 2014

**Host publication information**

Title of host publication: Proceedings of the 29th European Photovoltaic Solar Energy Conference and Exhibition, EU PVSEC 2014, September 22-26, 2014, Amsterdam, the Netherlands  
Publisher: European Environment Agency  
ISBN (Print): 3-936338-34-5

**Bibliographical note**

Proceedings can be downloaded via EU PVSEC website: https://www.eupvsec-proceedings.com/proceedings/dvd.html  
Contribution: organisation=orc,FACT1=1  
Portfolio EDEND: 2014-12-16  
Publisher name: European Environment Agency  
Source: researchoutputwizard  
Source-ID: 1291  
Research output: Scientific - peer-review › Conference contribution

Effect of plasma treated Ag/indium tin oxide anode modification on stability of polymer solar cells

**General information**

State: Published  
Ministry of Education publication type: A1 Journal article-refereed  
Organisations: Optoelectronics Research Centre, Research group: Surface Science, Frontier Photonics  
Authors: Augustine, B., Sliz, R., Lahtonen, K., Valden, M., Myllylä, R., Fabritius, T.  
Number of pages: 5  
Pages: 330-334  
Publication date: 2014  
Peer-reviewed: Yes

**Publication information**

Journal: Solar Energy Materials and Solar Cells  
Volume: 128  
ISSN (Print): 0927-0248  
Ratings:  
Scopus rating (2016): CiteScore 4.97 SJR 1.587 SNIP 1.71  
Scopus rating (2015): SJR 1.869 SNIP 1.896 CiteScore 5.16  
Scopus rating (2014): SJR 2.204 SNIP 2.396 CiteScore 5.87  
Scopus rating (2013): SJR 2.174 SNIP 2.582 CiteScore 5.58  
Scopus rating (2012): SJR 2.435 SNIP 2.707 CiteScore 5.25  
Scopus rating (2011): SJR 2.175 SNIP 2.638 CiteScore 5.16  
Scopus rating (2010): SJR 2.524 SNIP 2.121  
Scopus rating (2009): SJR 1.991 SNIP 1.977  
Scopus rating (2008): SJR 1.654 SNIP 1.458  
Scopus rating (2007): SJR 1.359 SNIP 1.488
Influence of surface hydroxylation on the oxidation of FeCr in O₂ and air

General information
State: Published
Ministry of Education publication type: B2 Part of a book or another research book
Organisations: Optoelectronics Research Centre, Research group: Surface Science
Authors: Hirsimäki, M., Hannula, M., Lahtonen, K., Urpelainen, S., Valden, M.
Number of pages: 2
Pages: 1-2
Publication date: 2014

Host publication information
Title of host publication: Max-Lab Activity Report 2013. Reports 2013 Synchrotron Radiation. Beamline I511-1
Place of publication: Lund, Sweden
Publisher: MAX-LAB
Links:
https://www.maxlab.lu.se/node/1913

Bibliographical note
Contribution: organisation=orc,FACT1=1<br/>Portfolio EDEND: 2014-09-10<br/>Publisher name: Elsevier BV
Source: researchoutputwizard
Source-ID: 125
Research output: Scientific › Article

Surface Modifications and Analysis Methods at Molecular Level

General information
State: Published
Ministry of Education publication type: A4 Article in a conference publication
Organisations: Optoelectronics Research Centre, Research group: Surface Science, Department of Physics, Research group: Ultrafast and intense lasers, Research group: Nanophotonics
Publication date: 2014

Host publication information
Title of host publication: Abstracts of the 28th International Conference on Surface Modification Technologies, SMT28, Tampere University of Technology, Tampere, Finland, June 16-18, 2014
Place of publication: Tampere
Publisher: Tampere University of Technology
Links:
In Situ XPS Studies of Electrochemically Negatively Polarized Molybdenum Carbide Derived Carbon Double Layer Capacitor Electrode

General information
State: Published
Ministry of Education publication type: A1 Journal article-refereed
Organisations: Optoelectronics Research Centre, Research group: Surface Science, Frontier Photonics
Authors: Tonisoo, A., Kruusma, J., Pärna, R., Kikas, A., Hirsimäki, M., Nommiste, E., Lust, E.
Number of pages: 10
Pages: A1084-A1093
Publication date: 2013
Peer-reviewed: Yes

Publication information
Journal: Journal of the Electrochemical Society
Volume: 160
Issue number: 8
ISSN (Print): 0013-4651
Ratings:
Scopus rating (2016): SJR 1.134 SNIP 0.867 CiteScore 2.97
Scopus rating (2015): SJR 1.037 SNIP 1 CiteScore 3.17
Scopus rating (2014): SJR 1.147 SNIP 1.206 CiteScore 3.36
Scopus rating (2013): SJR 1.151 SNIP 1.299 CiteScore 2.92
Scopus rating (2012): SJR 1.329 SNIP 1.296 CiteScore 2.61
Scopus rating (2011): SJR 1.33 SNIP 1.345 CiteScore 2.74
Scopus rating (2010): SJR 1.417 SNIP 1.312
Scopus rating (2009): SJR 1.45 SNIP 1.267
Scopus rating (2008): SJR 1.608 SNIP 1.416
Scopus rating (2007): SJR 1.58 SNIP 1.325
Scopus rating (2006): SJR 1.611 SNIP 1.54
Scopus rating (2005): SJR 1.519 SNIP 1.484
Scopus rating (2004): SJR 1.719 SNIP 1.706
Scopus rating (2003): SJR 1.962 SNIP 1.679
Scopus rating (2002): SJR 2.147 SNIP 1.646
Scopus rating (2001): SJR 1.651 SNIP 1.738
Scopus rating (2000): SJR 1.788 SNIP 1.708
Scopus rating (1999): SJR 1.657 SNIP 1.85
Original language: English
DOIs: 10.1149/2.042308jes

Optimization of interfacial oxidation properties of FeCr SOFC interconnect alloy

General information
State: Published
Ministry of Education publication type: B2 Part of a book or another research book
Organisations: Optoelectronics Research Centre, Research group: Surface Science
Authors: Ali-Löytty, H., Jussila, P., Hirsimäki, M., Valden, M.
Number of pages: 2
Pages: 1-2