Nanoscale aluminum dimples for light-trapping in organic thin-films

Goszczak, Arkadiusz Jaroslaw; Adam, Jost; Cielecki, Pawel Piotr; Fiutowski, Jacek; Rubahn, Horst-Günter; Madsen, Morten

Publication date: 2014

Document version: Accepted manuscript

Citation for published version (APA):

Terms of use
This work is brought to you by the University of Southern Denmark through the SDU Research Portal. Unless otherwise specified it has been shared according to the terms for self-archiving. If no other license is stated, these terms apply:

- You may download this work for personal use only.
- You may not further distribute the material or use it for any profit-making activity or commercial gain.
- You may freely distribute the URL identifying this open access version.

If you believe that this document breaches copyright please contact us providing details and we will investigate your claim. Please direct all enquiries to puresupport@bib.sdu.dk

Download date: 12. Dec. 2019
Integration of nanostructures in organic solar cells (OSC) has been investigated intensively in the past few years as an alternative way for enhancing the power conversion efficiency of the devices. Incorporating structured electrodes in the solar cell architecture holds potential for light absorption improvement in the active layer of the devices. A prospective, cheap and large-scale compatible method for structuring the electrodes in OSCs arises by the use of anodic aluminum oxide (AAO) membranes. In the present work, aluminum films of high purity and low roughness are formed via anodization of AAO membranes. The pore diameter of the AAO pattern, top view (a) and cross section (b), depends strongly on the anodization parameters (sample temperature, voltage, electrolyte). The formation of pores transfers a dimple-like pattern to the Al below the AAO (red circled area in (b)). Selective etching of the AAO in H₃PO₄/H₃PO₄ mixtures reveals the underlying nanoscale Al dimples, top view (c) and tilted cross section (d).

The anodization of Al in different electrolytes results in various dimple dimensions, average dimple diameters are 30nm for sulfuric (a), 90nm in oxalic (b) and 280nm in phosphoric (c). Dimple samples are covered with 200nm of PMMA and scanned with a 790nm femtosecond pulsed laser beam. Due to dimensional limitations of the dimples and thickness of the PMMA, local field enhancement from the edges of the dimples is more evident for dimples made from phosphoric electrolyte (f), rather than those made from sulfuric (d) and oxalic (e) electrolytes.

Our 3-D FDTD calculations, with 300nm dimple diameter and 200nm PMMA thickness, indicate a strong correlation between power, the concentration near the dimple edges and the initial ablation spots (Figure 3).

Motivation

Fabrication

**AFM characterization of Al dimples**

AFM characterization of various Al dimple samples has shown that the Al dimples consist of peaks that can reach up to 350nm in height (phosphoric). Different electrolyte acids lead to different dimple morphology, due to the anodization of the Al is the guiding force for the dimple structural formation.

**SEM characterization of Al dimples and ablation samples on Si substrate**

The anodization of Al in different electrolytes results in various dimple dimensions, average dimple diameters are 30nm for sulfuric (a), 90nm in oxalic (b) and 280nm in phosphoric (c). Dimple samples are covered with 200nm of PMMA and scanned with a 790nm femtosecond pulsed laser beam. Due to dimensional limitations of the dimples and thickness of the PMMA, local field enhancement from the edges of the dimples is more evident for dimples made from phosphoric electrolyte (f), rather than those made from sulfuric (d) and oxalic (e) electrolytes.

**Numerical Simulations (FDTD)**

Broadband, three dimensional (3-D) Finite-difference time-domain (FDTD) simulations support the experimental outcome. We employed a hexagonal, periodic lattice of spherically shaped Al dimples with a PMMA top layer. Perfectly matched layers (PML) sandwich the unit cell in z-direction, whereas Bloch periodic boundaries surround the unit cell in the layer plane. A plane wave source with normal incidence, polarized perpendicularly to the dimple ridges, excites the structure. A Fourier transformation leads to the (wavelength-dependent) electromagnetic field power distribution within the unit cell.

Our 3-D FDTD calculations, with 300nm dimple diameter and 200nm PMMA thickness, indicate a strong correlation between power, the concentration near the dimple edges and the initial ablation spots (Figure 3).

**Outlook**

It has been shown that Al dimples easily can be fabricated from AAO templates, and that such nanostructures exhibit light trapping effects. The dimples can potentially serve as nanostructured electrodes in P3HT:PCBM bulk heterojunction organic solar cells, and the fabrication of such OSC devices is currently under investigation. Preliminary results indicate that the organic blend covers homogeneously the Al dimples structures (Figure 6) while the Al dimple show improved absorbance compared to planar Al electrodes (Figure 7). The origin of this effect is from combined field-enhancement at the edges of the dimples along with diffuse scattering from the dimples.