ACT Node & WA Node NEWS

Providing nano and microfabrication facilities for Australia's researchers

Australian National Fabrication Facility

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Nanoantennas: Manipulating light at the nanoscale

Antennas are all around in our modern wireless society: they are the front-ends in satellites, cell-phones, laptops and other devices establishing communication by sending and receiving electromagnetic waves. While all these devices typically operate at frequencies from 300 GHz to as low as 3 kHz, according to Maxwell's equations the same principles of directing and receiving electromagnetic waves should work at various scales independently of the wavelength.

Thus, one may naturally ask *"Can an antenna send a beam of light?"* And the answer is *"Yes, a nanoantenna can!"*

However, nanoantennas have even more to offer than this: They can concentrate light in ultra-small nanoscopic volumes, thereby strongly enhancing interaction with nanoscale matter. Plus, they can efficiently link these spatially localised near fields with propagating optical fields and, by reciprocity, vice versa. Based on these principles nanoantennas are expected to play an important role in key applications like efficient quantum-light sources, photovoltaics, nonlinear optics, single-molecule detection, and as transmitting and receiving devices for on-chip optical networks. Yet, given the small dimensions of nano-antennas, their precision fabrication still remains a challenge and relies on state-of-the-art nanotechnology.

Nonlinear Physics Centre (NLPC) researchers at ANU, using ANFF ACT Node facilities, are developing next-generation optical nanoantennas for the unprecedented control of light at the nanoscale, including control of the bandwidth, directionality, and complex polarization state of the light emitted or absorbed by the nanoantennas.

For example, Fig. 1 (below) shows a tapered Yagi-Uda nanoantenna fabricated at the ANFF ACT facilities using electron-beam lithography, gold evaporation and a lift-off procedure [1].

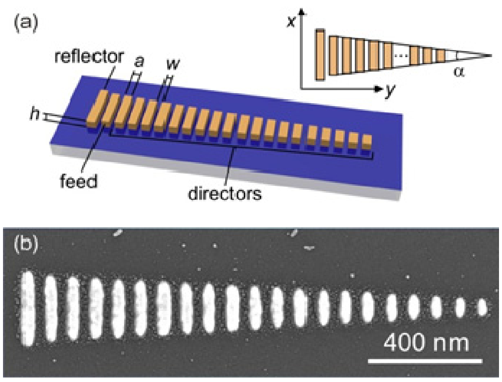

Fig. 1: (a) Design sketch and (b) scanning electron micrograph of a tapered Yagi-Uda nanoantenna for broadband unidirectional emission enhancement [1]

This nanoantenna has been predicted to provide broadband unidirectional emission enhancement from nanoemitters like quantum dots placed in direct vicinity of the gold nanorod ends. In addition, this type of nanoantenna is expected to offer a number of intriguing new functionalities like multichannel sensing and cascaded four-wave mixing. Crucially for the performance of this design, the centre-to-centre distance between neighbouring antenna elements is only 80 nm. NLPC researchers were able to reproducibly obtain such small distances while preserving a high structure quality by using a cold development procedure of the electron-beam resist at -10˚C. Also, the realised taper angle α of the fabricated nanoantenna is 6.6 degrees, which has been found to optimise the nanoantenna's directivity in numerical simulations. Using transmittance spectroscopy, and comparing the collected spectra to those of untapered reference structures, NLPC researchers were able to confirm the broad spectral bandwidth of this arrayed nanoantenna, laying the foundation for directional broadband quantum light sources and the nanontenna's other unique applications.

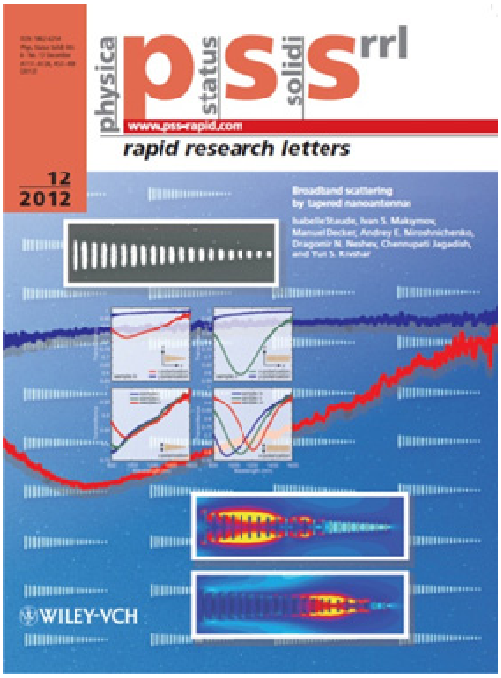

Fig. 2: Broadband nanoantennas have received a lot of attention from the media because of their unique application opportunities and interesting physical behaviour. NLPC results were highlighted on the front cover of the December 2012 issue of Physica Status Solidi Rapid Research Letters [1].

Hitting the 'send' button *emailing this newsletter to our subscribers is a very satisfying moment of my job! Our first issue (in Sept 2009) was sent out to just over 30 people - now we are approaching 300! And not just that - it is the fact that we report on new, exciting scientific developments enabled by researchers using the tools/facilities, and the expertise of our staff, at our nodes of the ANFF that have grown and developed over the same period as this newsletter.*

It is also satisfying to have our contributors take the time to write their stories in laymen's terms for all our readers to understand - much different to the manner in which they write for their 'real' journal articles. So, 'thanks' to Dr Isabelle Staude for this issue's feature article, and all our past contributors for their time and effort.

Also in this issue, a brief story that highlights another aspect of the value of, what is, a truly national facility. A piece of equipment unable to be installed at the Queensland Node in Brisbane has been shipped 4,500km across Australia to find a new home at the WA Node at UWA, Perth - and already it is producing some valuable output/results.

Next Issue:
due June 2013

ACT Node & WA Node info:

- The ACT Node specialises in III-V compound semi-conductors.
- The WA Node specialises in II-VI compound semi-conductors and MEMS.
- We can provide full support with the use of the equipment available.
- Full pricing policy and rates are available on the ANFF website at www.anff.org.au or contact us direct for more information - see contact details overleaf.

State-of-the-Art Thin Film Deposition Tool Transferred to ANFF WA Node

Sentech SI 500D Inductively Coupled Plasma Enhanced Chemical Vapour Deposition (ICPECVD) tool in full swing at the ANFF-WA fabrication facility. The tool is operated by postgraduate student Rohit Sharda.

With the aid of the Educational Investment Fund (EIF), ANFF-Qld acquired a state-of-the-art thin film deposition tool. A Sentech SI 500D Inductively Coupled Plasma Enhanced Chemical Vapour Deposition (ICPECVD) system was supplied from Germany by SENTECH Instruments GmbH and represents the leading edge for plasma deposition. The tool features exceptional plasma properties such as high density and low ion energy. A uniquely designed Planar Triple Spiral Antenna (PTSA) ICP plasma source allows efficient power coupling leading to low stress film growth with no damage of substrate, very low interface state density down to deposition temperatures of less than 100˚C allowing for outstanding properties of the deposited films. The substrate electrode with dynamic temperature control, in combination with He backside cooling and substrate backside temperature sensing, provides excellent stable process conditions over a wide temperature range from room temperature up to +300˚C.

However installation turned out to be not possible at ANFF-Qld and, in a ANFF inter-node collaborative effort, the capability was transferred, installed and commissioned at ANFF-WA within the Western Australian Centre for Semiconductor Optoelectronics and Microsystems (WACSOM).

The SI 500D plasma enhanced deposition tool is configured to deposit SiO_2, SiN_x, SiO_yN_x and *a*-Si films in a temperature range from room temperature up to 300˚C. The SI 500D is especially suited for the deposition of high efficient protection barriers on organic materials at low temperatures and damage free deposition of passivating films at well-defined temperatures. A large variety of substrates from wafers up to 8″ (200mm) diameter to parts loaded on carriers can be processed. The single wafer vacuum loadlock guarantees stable process conditions and allows for easy switching between processes.

Story by Mariusz Martynuik, Facility Manager - ANFF WA Node.

Despite their ability to provide many useful properties, planar nanoantennas like the tapered design shown in Fig. 1 have serious limitations, e.g. when it comes to out-of-plane directionality or for interacting with circularly polarized light. Circularly polarized light, in particular, is inherently connected to chiral structures, which are, by definition, three-dimensional (3D). However, it is technologically important as it has favourable properties for propagation in rough environments and is, for example, successfully used in current technology for watching 3D films in theatres (the light seen by the two eyes differs in its *'handedness'*, a property which, unlike linear polarization, is not destroyed when the viewer tilts their head). In fact, while nanoantenna designers have drawn lots of inspiration from RF antenna geometries in the past, some of the most successful macroscopic antennas, like highly directional dish antennas or (chiral) helical antennas, are actually 3D and cannot be transferred to the nanoscale by standard planar fabrication schemes. This lack of a flexible and robust 3D metal nanofabrication scheme also affects research into a variety of other dimensionality effects, like 3D tapers for light, magnetic coupling between nanoantenna elements, or dimensionality effects in fractal structures, which are currently almost completely unexplored for nanoantennas.

In order to overcome these limitations NLPC researchers have developed a novel hybrid fabrication approach combining the three-dimensionality from two-photon direct-laser writing with the small feature sizes, excellent metal quality, and capability of selective metallisation from electron-beam lithography based fabrication schemes [2]. A sketch illustrating the individual steps of this approach is shown in Fig. 3 (a) (above left).

Figure 3 (b-e) (above right) displays a variety of out-of-plane plasmonic nanostructures the NLPC have realised using this approach. In contrast to planar gold nanorods, the nanorods they have fabricated are curved out into the third dimension, supporting not only an electric dipole mode, but also a ring current which gives rise to a magnetic optical response. NLPC researchers studied the optical properties of their fabricated structures using transmittance spectroscopy and found a very good agreement with theoretical predictions for this magnetic mode. These results pave the way towards experimental realisation of a range of other previously out of reach 3D nanoantennas with unique functionalities that rely on entering the third dimension.

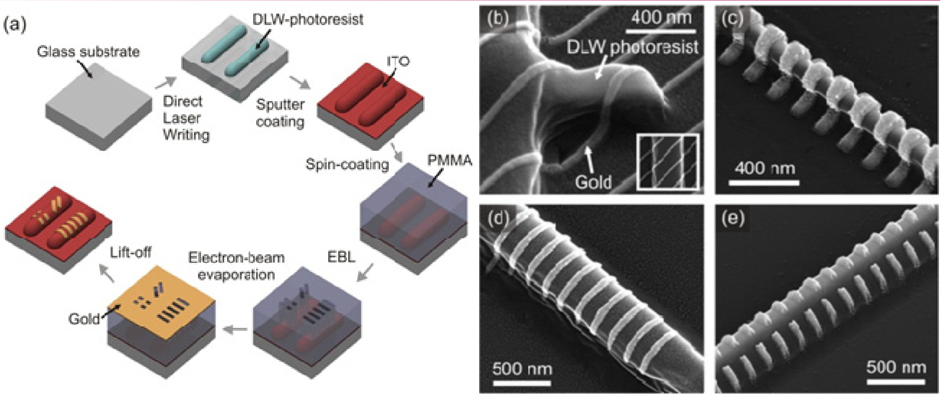

Fig. 3(a) above left - Schematic of the process steps of the hybrid 3D nano-fabrication approach: a glass substrate is pre-patterned using two-photon direct laser writing. Next, the photoresist structure is sputter-coated with Indium-Tin-Oxide (ITO) to make it conductive for electron-beam lithography and spin-coated with the electron-beam resist PMMA. The PMMA is then exposed by electron-beam lithography. A precision alignment procedure can be performed before electron-beam lithography to precisely place the written pattern on top of the photoresist template. After PMMA development, a gold evaporation step and a lift-off procedure are performed, altogether resulting in out-of-plane gold structures with truly nanoscopic feature sizes [2].

Article supplied and written by Dr Isabelle Staude, Research Fellow, Nonlinear Physics Centre, RSPE, ANU

References - *[1] I. Staude, et al, "Broadband scattering by tapered nanoantennas", Phys. Status Solidi RRL 6, 466-468 (2012).*
[2] I. Staude, et al, "Hybrid High-Resolution Three-Dimensional Nanofabrication for Metamaterials and Nanoplasmonics", Adv. Mater. Early View DOI: 10.1002/adma.201203564 (2012).

Australian National University

Research School of Physics & Engineering
The Australian National University
Canberra ACT 0200 Australia

T: +61 2 6125 7174
F: +61 2 6125 0511
E: fouad.karouta@anu.edu.au

ANFF
Australian National Fabrication Facility Ltd

ACT Node & WA Node

http://anff-act.anu.edu.au

The University of Western Australia
Achieve International Excellence

School of Electrical, Electronic & Computer Engineering
The University of Western Australia
Crawley WA 6009 Australia

T: +61 8 6488 1905
F: +61 8 6488 1095
E: mariusz.martyniuk@uwa.edu.au