AIT | Muthgasse 11 | 1190 Wien, Austria

Doc. Ing. Jaroslav Katolicky, PhD.
FSI Brno University of Technology
Technicka 2896/2
Czech Republic

BioSensor Technologies

Jakub Dostalek
AIT Austrian Institute of Technology GmbH
Muthgasse 11 | 1190 Wien, Austria
T +43(0) 664 2351773 | F F +43(0) 50550-4399
jakub.dostalek@ait.ac.at | www.ait.ac.at

7th November 2015

Report: Report on doctoral thesis titled "Application of plasmon polaritons in nanophotonics" submitted by Ing. Lukas Brinek

The doctoral thesis presents research that PhD candidate – Ing. Lukas Brinek – carried out at the Faculty of Mechanical Engineering, Brno University of Technology in the field of nanophotonics. It demonstrates successful preparation, simulations, and experimental characterization of several types of plasmonic structures. In addition, it shows initial steps towards their implementation to surface enhanced infrared absorption spectroscopy and to advanced fundamental near field optics studies. The thesis documents that the candidate participated in several projects where he prepared plasmonic nano-antennas with the resonant wavelengths tuned in visible and near infrared part of spectrum and he experimentally and theoretically investigated their near field and far field characteristics. The PhD candidate employed these structures for the investigation of the coupling between plasmonic modes and rich spectrum of absorption bands in near IR part of spectrum originating from vibrational transitions in silicon-rich oxinitride. He pursued experiments aimed at using cathodoluminescence coupled with scanning electron microscope for the mapping of near field of bright and dark modes of plasmonic nano-antennas that are resonant in the visible part of spectrum. The PhD candidate carried out exciting research and the examiner fully recommends accepting the thesis for defense at Brno University of Technology.

More detail comments to the thesis (doktorska prace) itself and to its short version (teze doktorske prace) can be found below. This section is structured based on the requirements the examiner received. It is meant to provide a feedback to the PhD candidate describing the weaknesses and strengths of the thesis.

Relevance of the research: Projects described in the thesis are well connected to rapidly developing research field of nanophotonics. This research holds potential to impact broad range of fields including data processing by highly integrated optical components and analytics that take advantage of novel technologies for detection and analysis of chemical and biological species. The thesis demonstrates that the candidate mastered state-of-the-art simulation and experimental tools in order to design and fabricate well controlled plasmonic nano-structures. The employing of prepared structures to fundamental studies of properties of these novel materials (near field mapping) and applications in surface-enhanced infrared spectroscopy (SEIRA) represent two hot topics in the current plasmonics research arena.

Research aims: The thesis lacks clearly defined aims. The relatively short introduction does not point out what are the barriers of the research and applications pursued up to now (the-state-of-the-art of research). The introduction is rather an overview of areas plasmonic community attempted to address over the last year without a discussion whether successfully if not. Therefore, it is also not clearly stated what are the key challenges in the plasmonics research and which specific problems the PhD candidate aims to address.

Used methods: The thesis documents that the candidate successfully mastered electron beam lithography and focused ion beam lithography for the preparation of metallic nanostructures. The thesis reveals solid knowledge gained in using these techniques as well as in broader fields of optics, numerical simulations, and optical spectroscopy. Based on this knowledge, PhD candidate carried out series of experimental and theoretical studies that concerned preparation of metallic nanostructures with tailored plasmonic properties. The prepared structures were optically characterized by measuring IR reflectivity spectra, scanning electron microscopy and cathodoluminiscence. These methods represent state-of-the-art tools used at the forefront research in plasmonics.

Impact of the thesis / scientific content:
The thesis shows novel results that are clearly beyond-the-state-of-art. A part of the results is at the preliminary stage and can provide sufficient basis to subsequent follow up projects. The work of PhD candidate resulted in numerous new observations and his work was reported in four papers (one first author and three co-author) published in peer reviewed journals (APL, Optics Express, Nanoletters) that are important for the plasmonics research community. In addition, two other papers are in preparation stage and 4 other papers were published in a local journal (Jemna mechanika optica).

Formal structure of the thesis:
The thesis does not have a usual structure consisting of: Introduction with the state-of-the-art of research field, research aims, methods, and results. Rather, these components are blended in the text and thus navigating though is sometime tedious. From the formal point of view, the thesis is written in good English with acceptable amount of typos. The following formal or minor issues should be corrected:

- Viruses are objects much bigger than 18 nm (stated on page 24, line 1)
- There are repeatedly defined same abbreviations through the whole thesis (e.g. SEIRA, EBL…)
- Through the whole thesis the term "dimer" is often mixed with "dimmer".
- Equation 3.1 – neff is defined as a complex number while wavelength is a real number. Thus there should be indicated that real part of neff is assumed in this equation.
- Figure 3.16 – lack of description of the inset in the graph.
- Discussion on page 39 of the data presented in Figure 3.16: this figure shows reflectivity curves from a SRON surface with attached plasmonic nano-antennas on the top with varied antenna geometry. It shows rich features in the spectrum with likely multiple resonances overlapping. In general, the signature of the coupling of light to surface plasmons can be a dip, peak or Fano resonance in the reflectivity spectrum. The examiner misses arguments why author attributes to the coupling the peaks (and not *e.g.* dip or Fano resonance). For instance, comparing with simulated reflectivity and absorption spectrum could elucidate this issue.
- Figure 3.18 and 3.19 – Units for $|E|^2$ are missing. In addition, information on what was the polarization of incident light assumed in these simulations is missing (e.g. unpolarized as in experiments).
- Concerning the discussion of absorption efficiency in SRON on page 42-43, the text may be clarified. It appears strange that the absorption efficiency in Figure 3.20 is >1 taking into account the way it is defined.
- Figure 3.21 shows an interesting observation that the maximum field enhancement $|E|^2$ does not translate to the maximum absorption efficiency. It would be worth of commenting on this.
- Section 3.5.1 indicates that there will be presented some simulation results supporting the spatially resolved cathodoluminiscence measurements. However, it seems not to be the case and thus this section is obsolete.
- In the application on prepared structures for SEIRA observation of SRON, a ratio of absorption feature strength and spectral width is used. Indeed, it is not clear to the examiner how such value was determined as several spectral features overlap. In addition, more detail discussion on how this parameter relate to the enhancement in the sensitivity of SEIRA measurement should be provided. According to examiner understanding, the presented data do not demonstrate such enhancement for the selected SRON material. Rather a complex behavior

of the coupled system of dipolar plasmonic antenna and multi-band wavelength absorption of selected material is demonstrated.
- At several places, term "golden" is used rather than "gold".

Comments to the short version of thesis (Teze disertacni prace): The short version of thesis does not follow the regular structure (state-of-the-art, aims, methods, results, conclusions). In addition, following changes would improve the readability of this document:

- The examiner obtained a document printed without colors, however, the text and figures give impression that color was intended to be used. The lack of colors, hinders the readability of the text.
- The majority of previous comments for the full length thesis apply for the short thesis as well.
- Figure 9 lacks units at vertical axis.

Singapore, 7.11.2015