Interdisciplinary investigations towards integration of active and passive sub-THz elements into a single monolithic circuit fabricated in advanced nitride technology

The increasing interest for high frequencies (HF) mainly comes from communication application and research interests from different scientific disciplines. Despite of many efforts in different R&D projects, at the certain point when increasing of the frequency, one can face a few critical obstacles, which significantly limits their developments. Our proposal is aimed to make interdisciplinary investigations on possibilities of integration of electronic elements in one chip designed and fabricated in gallium nitride based technology. Our target frequency is in the upper range of EHF band (extremely high frequencies [1]), i.e. above 100 GHz. In particular it aims to conduct an interdisciplinary research at sub-terahertz range (sub-THz: 0.1-0.3 THz), which is very attractive in HF engineering, electronics, semiconductor physics, and materials engineering. Basing on the previous works of consortium team members [2-3], their knowledge and expertise in research fields and disciplines, we propose the investigations, which can be efficiently working systems and fill this gap of lacking solid-state integrated systems at sub-THz.

Therefore, **our main scientific goal is to study possibilities to integrate passive radiating and active electronic elements in one chip designed and fabricated in gallium nitride based technology.** Besides of scientific problems to be solved described in the proposal, which usually appear with the increasing frequencies above 100 GHz and problems to integrate passive radiating and active parts into one technology, we propose to use wide band gap GaN semi-insulating substrate in both roles as the semiconducting substrate and the dielectric support for planar antennas (radiating passive elements). Also, we base our proposal on the preliminary results, which recently have been obtained at sub-THz range for passive elements on the GaN ammonothermal substrate. There, we have successfully observed the high gain of the antenna surrounded by designed metasurfaces. This result confirms feasibility of limitation of parasitic surface wave excitations by special designed passive samples that later on could be integrated with active components in the frame of the project. So, the **additional goal of this proposal is to develop specific sub-THz design concepts of gallium nitride based technology for the purpose of this integration.** Moreover, **we hypothesize** that basing on the current state of art, our knowledge and experience in the research fields, the rigorous numerical simulations, and our preliminary results **we are able to design, fabricate and investigate integrated system with active and radiating passive elements efficiently working above 100 GHz on GaN**. To the best of our knowledge, the proposed approach is pioneering and can be performed partially due to unique access to high quality R&D substrates and technologies available at IHPP PAS.

Significance of this project comes from the complexity and interdisciplinarity of the described problems resulting from technological limitations and the lack of high-quality samples at sub-THz range. Therefore we propose to gain knowledge using integration of passive and active elements. We foresee main research problems and important challenges, but basing on our experience in HF semiconductor physics and technology, applied physics or HF electronics, and preliminary results, we propose complex approach to solve them towards sub-THz integrated systems. We propose the work plan with defined tasks and scientific goals, based on the complementary competences, expertise, and used methodologies of two consortium partners, leaded by IHPP PAS (in semiconductor physics) and WUT (in HF engineering). Moreover, we do believe that already performed common research is the well-established base for realisation of this project.

We believe, that **the impact of the results on the interdisciplinary development of research fields and scientific disciplines**, will be in gaining understanding of new fundamental physical and HF electronic properties of integrated sub-THz circuits and interaction between active and passive parts at HF. **Broader impact of the project will be in the development of reliable integrated technology**, which can be later on a base for wireless systems beyond 5G.

[1] *Radio Regulations, 2020 Edition*, International Telecommunication Union.
[2] Y. Yashchyshyn, P. Bajurko, J. Sobolewski, P. Sai, A. Przewłoka, A. Krajewska, P. Prystawko, M. Dub, W. Knap, S. Rumyantsev, G. Cywiński, "Graphene/AlGaN/GaN RF Switch," *Micromachines* **2021**, vol. 12, no. 11, 1343, doi: 10.3390/mi12111343.
[3] P. Bajurko, J. Sobolewski, Y. Yashchyshyn, P. Sai, S. Rumyantsev, T. Narytnyk, G. Cywiński, "AlGaN/GaN Distributed Schottky Barrier Single-Pole Single-Throw Millimeter-Wave Switches," *IEEE Access*, vol. 11, pp. 125909-125917, 2023, doi: 10.1109/ACCESS.2023.3331222.