Dr. Peter Jeglič
Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
E-mail: peter.jeglic@ijs.si, Tel.: +386 41 395493, Website: ultracool.ijs.si

Ireneusz Grabowski
Director of Institute of Physics,
Nicolaus Copernicus University in Torun

Faculty of Science
Marko Hum
Department of Physics
Bijenička cesta 32, 10000 Zagreb
Croatia

Ljubljana, January 29, 2023

Evaluation of the doctoral thesis "Development of an optical frequency standard" submitted by Domagoj Kovačić

Dear Ireneusz Grabowski and Marko Hum,

On January 11, 2023 I received a copy of a thesis entitled "Development of an optical frequency standard" submitted for the DPhil. by Mr. Domagoj Kovačić. In reply to your request please find my assessment and recommendation for the submitted thesis.

The aim of the thesis is to improve the current technology of optical atomic clocks, which already serve as an most accurate time and frequency standards. In the introductory chapter, Domagoj Kovačić covers the fundamentals of optical atomic clocks and introduces the terminology. In Chapter 2, the candidate provides the theoretical background of the steps required to achieve clock operation, including Doppler cooling, magneto-optical traps, a detailed description and properties of different strontium isotopes, magic wavelength optical lattices, high-precision spectroscopy of the clock transition in strontium and finally the locking of the clock laser to clock transition. Chapter 3 is devoted to the experimental and theoretical study of photoionisation cross sections of atomic states used in optical clock cycle of 88Sr at the blue magic wavelength. In Chapter 4 the upgrade of existing optical clock is presented, which will allow simultaneous operation of both the bosonic and fermionic optical clocks. In Chapter 5 the candidate describes a fully operational fermionic optical clock that is compared to the bosonic counterpart. Chapter 6 is devoted to the evaluation of accuracy budget of the bosonic optical clock. The thesis is briefly concluded in Chapter 7.

This thesis presents both experimental and theoretical work the DPhil. candidate did during his three year stay at the Institute of Physics at the Nicolaus Copernicus University in Torun, Poland. Some of the most important results reported in the thesis are the following:
- A study of blue magic wavelength optical lattices at 390 nm in strontium optical clocks with an emphasis on experimental requirements to ensure Lamb-Dicke regime.
- A detailed examination of photoionisation induced losses of atoms in blue magic wavelength optical lattice.
- An upgrade of the existing Sr optical clock experimental setups that improved the stability and accuracy of the clocks.

Dr. Peter Jeglič
Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
E-mail: peter.jeglic@ijs.si, Tel.: +386 41 395493, Website: ultracool.ijs.si

- A fully operational fermionic clock up to the single frequency red MOT stage. This will allow to run the fermionic and bosonic clocks simultaneously and to perform measurements of the fermionic clock transition frequency by comparison with its bosonic counterpart.

The thesis is well presented, clear and lucid, and largely free of typographical errors. The scientific concepts are described logically and are easy to follow. In particular, Chapter 2 provides all the necessary theoretical background to understand the experiments presented in the subsequent chapters, meaning that the candidate has a really good knowledge of the subject. As minor shortcomings, I miss a little more in-depth discussion of open challenges and motivation for presented work in the Introductory chapter and an outlook in Conclusions.

The work of the candidate, as presented in the thesis, stands well in an international context. In this respect, I note that the work of the candidate has already been published in Optics Express. In addition, the DPhil. candidate contributed to the work on atom cooling with a frequency comb together with the Quantum technologies group at the Center for Advanced Laser Techniques at the Institute of Physics in Zagreb, Croatia, with publications in major peer-reviewed journals (Journal of the Optical Society of America B, Physical Review A and Scientific Reports). I find these results important for novel frequency comb applications, such as simultaneous multispecies cooling, multimode quantum memories, multispecies atom interferometers for space applications, and for achieving quantum degeneracy with new atomic species. These results are also important in the context of the presented thesis since they might in future significantly improve the precision of optical frequency standards, enable measurements of fundamental constants with unprecedented accuracy, improve tests of charge, parity and time reversal symmetry. To summarise, a total of four thesis related papers have been published by the candidate as principal or co-author.

I have no hesitation in recommending the award of a DPhil.

Yours sincerely,

Dr. Peter Jeglič
Head of cold atoms lab

PETER JEGLIČ

Digitally signed by PETER JEGLIČ
Date: 2023.01.30 16:03:07 +01'00'