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ABSTRACT
This report highlights PhotoSonus M+, a tunable wavelength laser system recently introduced and developed specifically for photoacoustic imaging applications, where the highest imaging depth and resolution are required.

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I. INTRODUCTION
Photoacoustic imaging is one of the fastest growing research areas of non-invasive, high-resolution, and high-contrast visualization of both superficial and deep tissues. This method has a number of advantages over widely used conventional research and diagnostic methods as it does not use hazardous irradiation such as x-rays and has a significantly higher imaging resolution than conventional ultrasound. Photoacoustic imaging has proven to be a very efficacious diagnostic modality of breast tumors, skin cancer, thyroid nodules, osteoarthritis and rheumatoid arthritis, early diagnosis of blood vessel disorders, and much more. In addition, photoacoustic imaging can be used for visualization of non-living objects, such as nondestructive inspection of the internal structure and property changes of composite materials and food inspection.

One of the most important components of any photoacoustic imaging system is a proper light source. EKSPA—a developer and manufacturer of reliable tunable wavelength laser systems—recently introduced the PhotoSonus M+ laser system developed specifically for photoacoustic imaging applications requiring a high imaging depth and resolution.

II. LASER PARAMETERS AND FUNCTIONALITY
The PhotoSonus M+ tunable wavelength laser system delivers more than 250 mJ at 680 nm, which is the highest pulse energy available in the market from an integrated optical parametric oscillator (OPO) system. The system contains a high-energy 10 Hz Q-switched laser, a parametric oscillator, power supply, and a cooling unit, all integrated into a single robust cart-type housing with customizable fiber coupled output to provide mobility, ease of use, and low maintenance cost. This allows the use of PhotoSonus M+ as a mobile stand-alone laser system that can be easily moved to another location, be it another laboratory or another bedside location. Expert knowledge, proprietary technological solutions, and many years of experience in the development and manufacturing of various tunable wavelength laser systems contributed to designing of a mobile, rigid, and highly reliable laser system (Fig. 1), which does not require reinstallation or any additional adjustment after its reallocation.

The wide gap-less wavelength tuning range 660–2300 nm makes PhotoSonus M+ an essential laser source for any photoacoustic imaging system. The tuning range can also be extended down to 330 nm. For real-time photoacoustic imaging applications, a proprietary Fast Wavelength Switching (FWS) feature is very useful. This unique feature enables us to pre-set a wavelength scanning cycle, which contains almost any number of wavelengths that are distributed in any order and at any step. Each laser shot can be emitted with a different wavelength. However, there is also a possibility to set the number of shots per wavelength up to 100. The maximum wavelength range that can be switched between two consecutive pulses is the entire extended signal range: 660–1300 nm. Wavelength switching accuracy is better than ±0.5 nm. For better synchronization with data acquisition equipment and easier wavelength real-time tracking, two synchronization signals are used by the FWS: One indicates the start of each scanning cycle, while the other indicates that the laser has fired a pre-set wavelength.
The highly flexible PhotoSonus M+ platform makes it easy to integrate and be used with any photoacoustic imaging system. It is fully motorized and computer controlled, with user trigger outputs and inputs and special options such as motorized switching between the OPO signal and idler through the same output, motorized attenuator, internal pulse energy meter, and electromechanical output shutter. For user convenience, the output of the PhotoSonus M+ laser has a fiber connector that could be customized for being coupled with almost any type of fiber bundle. A version of the PhotoSonus M laser system with slightly lower pulse energy and lower price (topped with 180 mJ pulse energy) is currently successfully used in preclinical photoacoustic tomography systems for imaging of small animal vasculature, organs, skeletal system, and skin (Fig. 2).

III. APPLICATIONS IN EARLY BREAST CANCER IMAGING

PhotoSonus M+ lasers are used in the EU funded PAMMOTH project (acronym of Photoacoustic Mammoscopy for evaluating screening-detected lesions in the breast), where EKSPLA is one of the project partners. PAMMOTH’s objective is to develop, validate, and begin exploitation of a dedicated breast imaging device for a significant impact in breast cancer early diagnosis. The proposed device combines non-invasive 3D photoacoustic imaging and ultrasound imaging. From the ultrasound mode, the radiologist can visualize anatomical features and extent of tumors, and from the multi-wavelength photoacoustic mode, he/she can assess tumor vascularity. Quantitative spectroscopic photoacoustic images are extracted off-line, providing the radiologist with information relating to tumor physiology and function such as angiogenesis and hypoxia.

The latest clinical prototype contains a modified twin mutually synchronized PhotoSonus M+ laser system, which can provide a max combined pulse energy of 500 mJ while operating at 10 Hz, or 250 mJ at 20 Hz. The output of such a system is coupled into a fiber bundle with one input at the laser end and 40 separate fiber outputs that are evenly distributed across the imaging bowl where a patient’s breast is immobilized during the photoacoustic mammoscopy examination. A clinical demonstration trial of the latest generation of the PAMMOTH imager equipped with the modified twin PhotoSonus M+ laser systems has just started at the Medisch Spectrum Twente Hospital (The Netherlands) (Fig. 3). Despite the significant instrumentation progress, the entire system is not yet optimized completely; however, the first acquired photoacoustic images are promising for the optimal expected imaging depth to exceed 50 mm and image resolution to exceed 0.35 mm. Examination of one breast takes less than 3 min.

IV. SUMMARY

The PhotoSonus M+ laser system is proving to be an excellent tunable wavelength irradiation source suitable for high depth and high-resolution photoacoustic imaging in a large area of live tissues.
REFERENCES

1 See https://www.pammoth-2020.eu for Photoacoustic Mammoscopy for evaluating screening-detected lesions in the breast.