VIETNAM NATIONAL UNIVERSITY, HANOI
VNU UNIVERSITY OF ENGINEERING AND TECHNOLOGY

SOCIALIST REPUBLIC OF VIETNAM
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INFORMATION ON DOCTORAL THESIS

1. Full name : Phan Hoang Anh..... 2. Sex: Male

3. Date of birth: November 3, 1996..... 4. Place of birth: Hanoi .....

5. Admission decision number: 496/QĐ-CTSV Dated: July 1, 2021

6. Changes in academic process: Extension of study duration by 24 months (2 years) under Decision No. 1487/QĐ-ĐHCN dated July 22, 2024, issued by the Rector of the University of Engineering and Technology.

7. Official thesis title: Research and development of Lab-on-a-Chip (LoC) device to detect and quantify lung cancer cells

8. Major: Electronics Engineering..... 9. Code: 9520203

10. Supervisors:

Supervisor: Assoc. Prof. Dr. Nguyen Hoang Hai, Vietnam National University, Hanoi

Co-supervisor: Prof. Dr. Chu Duc Trinh, University of Engineering and Technology

11. Summary of the **new findings** of the thesis:

The dissertation originates from the fact that lung cancer is the leading cause of cancer-related mortality, in which early detection of metastatic cancer cells plays a decisive role in treatment effectiveness. The main research subject of the dissertation is the A549 lung cancer cell line, which is separated and quantified using a multifunctional integrated Lab-on-a-Chip system, aiming toward point-of-care testing solutions.

The dissertation adopts a multidisciplinary approach combining numerical simulation, microsystem design and fabrication, and experimental validation to study and develop an integrated Lab-on-a-Chip system for detecting circulating lung cancer cells in blood. These methods are implemented in a coordinated manner to address physical, technical, and data-processing challenges in microfluidic environments characterized by weak signals and high noise. Numerical simulations are carried out using COMSOL Multiphysics software to model electromagnetic fields, microfluidic flow dynamics based on the Navier–Stokes equations, and particle/cell trajectories. Simulation results are used to optimize

microchannel structures, electrode layouts, and operating parameters prior to fabrication and experimentation.

The microfluidic system is fabricated using standard microfabrication techniques, in which gold electrodes are patterned by photolithography and wet etching, while PDMS microchannel structures are fabricated using soft lithography. Functional modules are then integrated into a complete chip system, ensuring geometric precision and operational stability. The dissertation successfully addresses key scientific and technical challenges in rare cancer cell detection by designing, fabricating, and validating a multifunctional integrated Lab-on-a-Chip platform. The system includes magnetic separation modules in structured microchannels, inertial flow regulation, oil-in-water droplet encapsulation of cells, and impedance sensing using microelectrodes, contributing to increased automation and reduced device size. Experimental results demonstrate high separation and recovery efficiency for model lung cancer cells. The average purity reaches 99.1% when separating A549 cells from mixtures with HeLa cells, while capture efficiency ranges from 80% to 100% depending on the size of magnetic beads used, demonstrating the flexibility of the proposed method.

The dissertation also masters droplet control techniques and successfully proposes and implements an on-demand droplet separation and routing method based on the combination of dielectrophoretic force and electrohydrodynamic effects. This technique provides a foundation for high-precision single-cell analysis and microscale biological applications. In addition, the application of machine learning models and computer vision enables automation of cell identification and counting processes. The algorithms achieve accuracy above 88% in classifying cell signals against background noise and 96.25% in bead counting within droplets, confirming the effectiveness and reliability of the proposed system.

On this basis, the dissertation achieves the following new results and contributions:

- Successful integration and fabrication of a complete microfluidic chip system capable of detecting and counting lung cancer cells, including functional modules for magnetic–inertial cell separation, droplet encapsulation, impedance-based cell detection and counting, and machine-learning-based signal classification.

- Proposal and development of novel methods for cell detection, classification, and separation using electromagnetic techniques and image processing, effectively exploiting machine learning models to enhance system accuracy and reliability.

12. Practical applicability:

The proposed LoC system provides a non-invasive, low-cost liquid biopsy tool that is easy to deploy in mobile healthcare facilities. The research results not only address challenges in rare cell isolation but also open up broad application potential in early cancer diagnosis and treatment monitoring in Vietnam, contributing to bridging technological innovation with clinical biomedical applications.

13. Further research directions:

Future research directions include conducting preclinical and clinical trials using real patient samples to evaluate the accuracy, repeatability, and reliability of the system compared with current standard methods. In parallel, it is necessary to develop standard operating procedures, quality evaluation criteria, and standardization requirements as a basis for technology transfer and practical application.

14. Thesis-related publications:

[1] Hoang Anh Phan, Anh Thi Nguyen, Loc Do Quang, Tung Bui Thanh, Chun-Ping Jen, Trinh Chu Duc, "Image-based machine learning quantitative evaluation of bead-cell binding interaction," (2025), Sensors and Actuators A: Physical, Vol. 367, 116123.

[2] Hoang Anh Phan, Kien Nguyen, Phong Tuan Pham, Loc Do Quang, Hang Bui Thu, Dang Bao Lam, Chun-Ping Jen, Tung Bui Thanh, Trinh Chu Duc, "On-demand electrostatic droplet sorting and splitting," (2025), Sensors and Actuators A: Physical, Vol. 385, 116311.

[3] Hoang Anh Phan, Tan Van Duong, Thien Vu Do, Tam Dang Tran Minh, Duong Bui Quang, Hieu Van Dang, Hoa Ngo Khanh, Tuan Vu Quoc, Hang Nguyen Thu, Hanh Nguyen Van, et al., "A self-driving microscopy system for intelligent in vitro imaging of oocyte maturation", (2026), Measurement, 121232. (Q1 Journal)

[4] Hoang Anh Phan, Nguyen Van Phu, Tung Le Thanh, Van Tan Duong, Anh Phuc Dao, Van Dai Pham, Loc Do Quang, Thanh Tung Bui, Duc Trinh Chu, "Machine Learning-based Single-cell Analysis Using Microfluidic Impedance Flow Cytometer," (2025), VNU Journal of Science: Mathematics – Physics, Vol. 41, No. 2.

[5] Hoang Anh Phan, Nguyen Dang Pham, Loc Quang Do, Tung Thanh Bui, Hai Hoang Nguyen, Trinh Duc Chu, "Machine learning-based bead enumeration in microfluidics

droplets enhances the reliability of monitoring bead encapsulation toward single-cell sorting applications," (2024), Microfluidics and Nanofluidics, Vol. 28, No. 8 (Article 71).

[6] Hoang Anh Phan, Loc Quang Do, Thanh Tung Bui, Thang Nguyen Van, Hoang Hai Nguyen, Trinh Chu Duc, "Automated detection and enumeration of bead encapsulation in microfluidic droplets based on deep learning," (2024), International Journal of Nanotechnology, Vol. 21, No. 7–12, pp. 609–621.

[7] Hoang-Anh Phan, Anh Nguyen Thi, Nguyen Pham Dang, Hien Vu-Dinh, Bao Lam Dang, Tung Thanh Bui, Chun-Ping Jen, Loc Do Quang, Hai Hoang Nguyen, Trinh Chu Duc, "Magnetic Bead Conjugated Lung Tumor Cell Binding Efficiency Assessment Based on Deep-Learning Approach," (2023), Proceedings of the 1st International Conference on Health Science and Technology (ICHST), pp. 1–6.