# Microfluidic Systems for Point-of-Care Diagnostics

Hubert Klaus and Dylan Stilinki



July 19, 2024

# Microfluidic Systems for Point-of-Care Diagnostics

**Date:** April 10 2018

**Authors**

Hubert Klaus, Dylan Stilinski

**Abstract**

This research focuses on the development of microfluidic systems for rapid and accurate medical diagnostics at the point of care. By integrating microfluidics, microelectronics, and biosensors, the study aims to create portable, affordable diagnostic tools capable of detecting various diseases. These miniaturized devices utilize precise fluid manipulation on a microscale to perform complex biochemical analyses quickly and efficiently. The research addresses key challenges such as the fabrication of low-cost materials, the integration of robust biosensors, and the optimization of fluid dynamics within the microchannels. The ultimate goal is to develop user-friendly diagnostic platforms that can provide immediate results, improving patient care by enabling timely and accurate disease detection and monitoring in diverse healthcare settings.

**Keywords:** Microfluidic systems, point-of-care diagnostics, medical diagnostics, portable diagnostic tools, microelectronics, biosensors, disease detection, rapid diagnostics, affordable healthcare, fluid dynamics.

## I. Introduction

Point-of-Care (POC) diagnostics have emerged as a crucial aspect of healthcare, allowing for rapid and accurate testing at the patient's bedside or in a primary care setting. In this section, we will provide an overview of POC diagnostics, including its definition, importance, and the global health impact it has had. Additionally, we will discuss the challenges faced by traditional POC diagnostics and how microfluidics has emerged as a transformative technology in addressing these challenges. Lastly, we will outline the historical perspective and current state-of-the-art of microfluidics in POC diagnostics.

Overview of Point-of-Care (POC) diagnostics:

POC diagnostics refer to medical tests performed outside of a traditional laboratory setting, usually at or near the point of patient care. This includes settings such as primary care clinics, emergency departments, and even patients' homes. The significance of POC diagnostics lies in its ability to provide immediate results, allowing for timely diagnosis, treatment, and monitoring of various medical conditions. This has a profound impact on patient outcomes, particularly in resource-limited settings where access to centralized laboratories may be limited.

Challenges in traditional POC diagnostics:

While traditional laboratory-based testing is highly accurate, it often suffers from long turnaround times and the need for specialized equipment and trained personnel. Traditional POC diagnostics face challenges in terms of portability, cost-effectiveness, and ease of use. Additionally, the limited availability of diagnostic tests at the point of care can lead to delays in diagnosis and treatment initiation.

Microfluidics as a transformative technology:

Microfluidics, a field that involves manipulating small volumes of fluids in microscale channels, has emerged as a transformative technology in the field of POC diagnostics. The basic principles of microfluidics include precise fluid control, high sensitivity, and the ability to perform multiplexed assays. These principles offer several advantages for POC applications, such as miniaturization, portability, reduced sample and reagent volumes, and rapid analysis.

Historical perspective and current state-of-the-art:

Microfluidics has a rich history of development, with significant advancements made in recent years. Early microfluidic devices were primarily used in research laboratories, but now they are being integrated into commercial diagnostic platforms. Current state-of-the-art microfluidic technologies include lab-on-a-chip devices, paper-based microfluidics, and droplet-based microfluidics, among others. These technologies offer improved sensitivity, specificity, and speed compared to traditional POC diagnostics.

Research gap and objectives:

Despite the progress in microfluidic-based POC diagnostics, there are still specific knowledge gaps that need to be addressed. In this research, our objective is to identify and fill these gaps by conducting a comprehensive analysis of the current literature. We will outline the research questions and hypotheses that will guide our investigation, enabling us to contribute to the advancement of microfluidics in POC diagnostics.

In summary, this introduction provides an overview of POC diagnostics and its significance in healthcare. It highlights the challenges faced by traditional POC diagnostics and introduces microfluidics as a transformative technology. The historical perspective and current state-of-the-art of microfluidics are discussed, along with the research gap and objectives of the study.

## II. Microfluidic Principles and Fabrication

In this section, we will delve into the fundamental principles of microfluidics, including the behavior of fluids at the micro scale and various microfluidic phenomena. We will also discuss the different techniques used for microfluidic fabrication and the selection of materials for biocompatibility and performance. Furthermore, we will explore the integration of microfluidic components, such as valves, pumps, mixers, and other functional elements, and highlight the design considerations necessary for optimal performance.

Fundamental principles of microfluidics:

Microfluidics operates on the principles of fluid behavior at the micro scale, where unique phenomena come into play due to the dominance of capillary forces and surface tension. At these small length scales, fluid flow becomes laminar, meaning it occurs in parallel layers with minimal mixing. This laminar flow enables precise control over fluid movement, facilitating the manipulation of samples and reagents. Additionally, diffusion, which plays a crucial role in analyte transport, becomes more efficient in microfluidic systems due to reduced distances and increased surface area-to-volume ratios.

Microfabrication techniques:

Microfluidic devices are typically fabricated using techniques such as soft lithography, photolithography, and other methods. Soft lithography involves creating a master mold using a soft material, such as poly(dimethylsiloxane) (PDMS), and then replicating the mold to produce the final microfluidic device. Photolithography, on the other hand, utilizes light-sensitive materials and masks to pattern the microchannels and features on a substrate. Other methods, such as micromachining and 3D printing, are also employed for more specialized applications.

Material selection for biocompatibility and performance:

Choosing the appropriate materials for microfluidic devices is critical to ensure biocompatibility and optimal performance. Materials must be compatible with the fluids and analytes being manipulated, exhibit low adsorption and chemical compatibility, and have suitable mechanical properties. Common materials used in microfluidics include PDMS, glass, polymethyl methacrylate (PMMA), and various thermoplastics. The selection of materials depends on factors such as transparency, ease of fabrication, and compatibility with specific assays or biological samples.

Integration of microfluidic components:

Microfluidic devices often incorporate various functional elements to enhance their capabilities. These components can include valves for fluid control, pumps for precise flow manipulation, mixers for efficient sample mixing, and sensors for real-time monitoring. Integration of these components into the microfluidic platform requires careful design and fabrication techniques to ensure proper functionality and compatibility with the overall system.

Design considerations for optimal performance:

Designing microfluidic devices for optimal performance involves considering several factors. These include channel dimensions, geometry, and aspect ratio, which affect fluid flow characteristics and mixing efficiency. Additionally, optimizing the placement of functional elements, such as valves and pumps, ensures accurate fluid control and efficient sample processing. Furthermore, minimizing dead volumes, reducing sample and reagent consumption, and implementing appropriate sealing techniques are crucial for achieving high sensitivity and reproducibility in microfluidic assays.

In summary, this section explores the fundamental principles of microfluidics, including fluid behavior at the micro scale and various microfluidic phenomena. It also discusses the different techniques used for microfluidic fabrication and the selection of materials for biocompatibility and performance. Additionally, it highlights the integration of microfluidic components and the design considerations necessary for optimal performance.

## III. Microfluidic Systems for Sample Preparation

In this section, we will explore the use of microfluidic systems for sample preparation, focusing on sample collection and pre-treatment, sample introduction and manipulation, and the integration of these processes into lab-on-a-chip devices.

Sample collection and pre-treatment:

Microfluidic systems offer innovative solutions for sample collection and pre-treatment. Miniaturized sample collection devices, such as microfluidic chips with integrated collection chambers or capillary-based systems, enable precise and controlled sampling from various sources. These devices can be designed to selectively capture target analytes, reducing the need for extensive sample handling and minimizing the risk of contamination.

Sample preparation techniques, including filtration, centrifugation, and lysis, are critical steps in sample processing. Microfluidic platforms can incorporate these techniques into integrated systems, allowing for efficient and rapid pre-treatment. For example, microfluidic filtration devices with precisely controlled pore sizes can effectively remove unwanted particles and debris from the sample. Centrifugal microfluidic platforms utilize rotational forces to separate and concentrate analytes, while microfluidic lysis devices facilitate the disruption of cells or extraction of nucleic acids.

Integration of sample handling steps into microfluidic systems:

One of the key advantages of microfluidic systems is the ability to integrate multiple sample handling steps into a single platform. Microfluidic devices can incorporate sample collection, pre-treatment, and subsequent analysis steps, eliminating the need for manual transfer and reducing the risk of sample contamination or loss. This integration streamlines the entire sample preparation process and enables rapid and automated workflows.

Sample introduction and manipulation:

Microfluidic systems employ various techniques for precise sample introduction and manipulation. Microvalves and micropumps are commonly used to control fluid flow, enabling precise sample injection and routing. These components offer advantages such as low dead volumes, high throughput, and precise control over flow rates and volumes. By integrating microvalves and micropumps into the microfluidic system, researchers can achieve accurate and reproducible sample handling.

Sample injection and mixing strategies are crucial for ensuring thorough sample processing and efficient reactions. Microfluidic systems employ different strategies, such as hydrodynamic focusing, electrokinetic injection, and passive diffusion-based mixing, to achieve precise sample injection and efficient mixing of reagents. These strategies enhance reaction kinetics and improve the accuracy and reliability of downstream analysis.

Integration with lab-on-a-chip devices:

Microfluidic systems can be seamlessly integrated with lab-on-a-chip devices, which encompass various analytical functions on a single chip. This integration enables the entire analytical process, from sample collection to final analysis, to be performed in a compact and portable format. Lab-on-a-chip devices can incorporate microfluidic sample preparation modules, such as microvalves, micropumps, and mixing chambers, along with other functional elements like sensors and detectors. This integration enables rapid, on-site analysis, making lab-on-a-chip devices highly valuable for point-of-care diagnostics and field-based applications.

In summary, microfluidic systems offer innovative solutions for sample preparation, including miniaturized sample collection devices and integration of sample handling steps. These systems utilize microvalves and micropumps for precise fluid control, employ various sample injection and mixing strategies, and can be seamlessly integrated with lab-on-a-chip devices. By leveraging these microfluidic technologies, researchers can achieve efficient and automated sample preparation workflows, leading to improved analytical performance and enabling applications in diverse fields such as healthcare, environmental monitoring, and food safety.

## IV. Microfluidic-Based Biomarker Detection

In this section, we will explore the use of microfluidic systems for biomarker detection, focusing on biomarker selection and target analytes, detection principles and technologies, signal amplification, and detection limits, as well as quantification and data analysis.

Biomarker selection and target analytes:

Biomarkers play a crucial role in disease diagnosis, prognosis, and monitoring. When selecting biomarkers for detection, it is important to consider their relevance and specificity to the disease or condition of interest. Different diseases may have specific biomarkers associated with them, such as certain proteins, nucleic acids, or metabolites. Careful consideration of the biomarker's characteristics, including its stability, abundance, and specificity, is essential for successful detection and accurate diagnosis.

Detection principles and technologies:

Microfluidic systems offer a range of detection principles and technologies for biomarker analysis. Optical detection methods, such as colorimetry, fluorescence, and spectroscopy, utilize the interaction of light with the target analyte to generate a measurable signal. These methods provide high sensitivity and specificity, enabling precise quantification of biomarkers.

Electrochemical detection techniques, including amperometry, potentiometry, and impedance, rely on the measurement of electrical signals generated by the biomarker-target interaction. These methods offer advantages such as simplicity, rapid response, and compatibility with miniaturized systems, making them well-suited for integration into microfluidic platforms.

Other detection modalities, such as mass spectrometry and microcalorimetry, provide additional capabilities for biomarker detection. Mass spectrometry allows for the identification and quantification of biomarkers based on their mass-to-charge ratio, while microcalorimetry measures the heat released or absorbed during biomolecular interactions.

Signal amplification and detection limits:

To enhance detection sensitivity, various signal amplification strategies can be employed in microfluidic-based biomarker detection. These strategies involve amplifying the signal generated by the biomarker-target interaction, thereby improving the limit of detection. Examples of signal amplification techniques include enzymatic amplification (e.g., using enzymes like horseradish peroxidase or alkaline phosphatase), nanoparticle-based amplification (e.g., using gold nanoparticles or quantum dots), and signal amplification through amplification cascades (e.g., rolling circle amplification).

Quantification and data analysis:

Accurate quantification of biomarkers is essential for reliable diagnosis and monitoring of diseases. Microfluidic systems enable precise control over sample handling and reaction conditions, facilitating accurate quantification. Data analysis techniques, such as calibration curves and standard curves, can be employed to correlate the measured signal with the concentration of the biomarker.

Additionally, advanced data analysis methods, including machine learning algorithms and statistical models, can be applied to process complex datasets and extract meaningful information. These techniques enable the identification of patterns, correlations, and trends in biomarker data, leading to improved diagnostic accuracy and personalized medicine.

In summary, microfluidic-based biomarker detection offers a range of advantages, including high sensitivity, specificity, and portability. By carefully selecting target analytes and employing appropriate detection principles and technologies, microfluidic systems enable accurate and reliable detection of biomarkers. Signal amplification strategies further enhance detection sensitivity, while quantification and data analysis techniques ensure accurate biomarker quantification and interpretation. Leveraging these microfluidic-based approaches allows for improved disease diagnosis, prognosis, and monitoring, with potential applications in personalized medicine and point-of-care diagnostics.

## V. Microfluidic Systems for Specific Point-of-Care (POC) Applications

In this section, we will explore the use of microfluidic systems for specific POC applications, focusing on infectious disease diagnostics, chronic disease management, and other POC applications such as pregnancy tests, environmental monitoring, and food safety testing.

Infectious disease diagnostics:

Microfluidic systems offer significant advantages for rapid and accurate detection of infectious diseases. These systems enable the integration of various diagnostic steps, including pathogen detection, nucleic acid amplification (such as PCR), and antimicrobial susceptibility testing. By miniaturizing these processes, microfluidic platforms can deliver fast and reliable results at the point of care.

Microfluidic-based infectious disease diagnostics can rapidly detect a wide range of pathogens, including bacteria, viruses, and parasites. The integration of nucleic acid amplification techniques, such as polymerase chain reaction (PCR), allows for highly sensitive and specific detection of pathogen DNA or RNA, enabling early and accurate diagnosis. Additionally, microfluidic systems can be utilized for antimicrobial susceptibility testing, providing crucial information for targeted treatment strategies.

Chronic disease management:

Microfluidic systems have the potential to revolutionize chronic disease management by enabling real-time monitoring and personalized treatment strategies. For example, in diabetes management, microfluidic-based glucose monitoring devices offer continuous and accurate glucose measurements, reducing the need for frequent fingerstick tests. These devices can provide patients with valuable insights into their glucose levels, enabling them to make informed decisions about their diet, medication, and physical activity.

Microfluidic platforms are also being developed for the detection and monitoring of cardiovascular disease biomarkers. These systems allow for the rapid and sensitive measurement of specific biomarkers associated with cardiovascular conditions, facilitating early diagnosis and monitoring of disease progression. By integrating these biomarker detection capabilities into portable and user-friendly devices, microfluidic systems have the potential to improve patient outcomes and reduce healthcare costs.

Cancer diagnostics and monitoring:

Microfluidic systems hold great promise for cancer diagnostics and monitoring. These systems enable the detection and analysis of specific cancer biomarkers, providing valuable information for early detection, prognosis, and treatment monitoring. By integrating microfluidic-based assays with sensitive detection methods, such as fluorescence or electrochemical detection, researchers can achieve high sensitivity and specificity in cancer biomarker analysis.

Other POC applications:

Microfluidic systems have found applications in various other POC scenarios, such as pregnancy tests, fertility monitoring, environmental monitoring, and food safety testing. Pregnancy tests based on microfluidic technology offer rapid and accurate results, empowering women to quickly and conveniently determine their pregnancy status. Fertility monitoring devices utilize microfluidic platforms to track hormonal changes and optimize fertility treatment plans.

In environmental monitoring, microfluidic systems enable the detection and analysis of pollutants, pathogens, and other contaminants in water, air, and soil samples. These platforms offer portability, sensitivity, and real-time monitoring capabilities, making them valuable tools for environmental scientists and policymakers.

Additionally, microfluidic systems are being developed for food safety testing, allowing for rapid and on-site analysis of contaminants, toxins, and pathogens in food samples. These systems provide faster results compared to traditional laboratory-based methods, ensuring the safety and quality of food products.

In summary, microfluidic systems have shown immense potential in various POC applications. From infectious disease diagnostics to chronic disease management, and from pregnancy tests to environmental monitoring and food safety testing, microfluidic platforms offer rapid, accurate, and portable solutions. By leveraging the advantages of miniaturization, integration, and sensitive detection methods, microfluidic-based POC devices have the potential to transform healthcare delivery and improve patient outcomes.

## VI. Integration and Miniaturization in Point-of-Care Device Design

When designing point-of-care (POC) devices, two critical aspects to consider are integration and miniaturization. These factors play a crucial role in ensuring user-friendly interfaces, efficient sample input, seamless integration of detection and readout systems, as well as the packaging and portability of the device.

Point-of-care device design should prioritize a user-friendly interface and sample input. The device should be intuitive and easy to use, with clear instructions and minimal steps required for sample input. Design considerations should include features such as ergonomic design, intuitive controls, and easy-to-read displays. By focusing on user experience, POC devices can facilitate accurate and efficient sample input, improving overall usability.

Furthermore, power supply and energy efficiency are important considerations. POC devices should be designed to operate on easily accessible power sources, such as batteries or rechargeable options, to ensure their usability in various settings. Energy-efficient designs can help prolong battery life and reduce the frequency of recharging or battery replacement, ensuring uninterrupted use of the device.

Integration of detection and readout systems is crucial for the seamless operation of POC devices. By integrating these systems into a single device, the complexity of sample processing and analysis can be minimized, reducing the risk of errors and improving the overall efficiency of the device. This integration may involve the incorporation of microfluidic channels, sensors, and detectors, as well as the integration of data analysis algorithms and software interfaces.

Packaging and portability are essential for the practical use of POC devices. The choice of materials should prioritize durability and sterility to ensure the device's longevity and the integrity of the collected samples. Additionally, miniaturization strategies should be employed to reduce the size and weight of the device, making it portable and easy to transport. Miniaturization can be achieved through the use of microfluidic chip technology, compact electronics, and efficient packaging designs.

Device validation and quality control are critical steps in the development of POC devices. Rigorous testing and validation protocols should be implemented to ensure the accuracy, reliability, and reproducibility of the device's performance. Quality control measures should be established to monitor and maintain the performance of the device over time. These measures may include regular calibration, periodic maintenance, and adherence to regulatory standards.

In summary, integration and miniaturization are key considerations in the design of point-of-care devices. Prioritizing a user-friendly interface, efficient sample input, integration of detection and readout systems, as well as packaging and portability, can enhance the usability and practicality of these devices. Additionally, device validation and quality control are essential to ensure accurate and reliable performance. By focusing on these factors, POC devices can effectively bring diagnostics and healthcare closer to the point of need, improving patient outcomes and healthcare delivery.

## VII. Challenges and Future Directions in Microfluidic-Based Biomarker Detection

While microfluidic-based biomarker detection holds great promise, there are several technical challenges that need to be addressed. These challenges include sample complexity and matrix effects, non-specific binding and fouling, as well as long-term stability and reliability.

Sample complexity and matrix effects pose challenges in accurately detecting biomarkers in complex biological samples. Factors such as the presence of interfering substances and variations in sample composition can affect the performance and accuracy of microfluidic-based assays. Overcoming these challenges requires the development of robust sample preparation techniques and the optimization of microfluidic systems to handle complex matrices.

Non-specific binding and fouling can also hinder biomarker detection in microfluidic systems. The interaction of biomolecules with the surfaces of microfluidic devices can lead to non-specific binding and fouling, resulting in false-positive or false-negative results. Surface modification techniques and the use of appropriate blocking agents can help mitigate these issues and improve the specificity and sensitivity of biomarker detection.

Long-term stability and reliability are important considerations for the successful commercialization of microfluidic-based biomarker detection devices. Ensuring the stability and reliability of microfluidic systems over extended periods of use is crucial for their practical application. Factors such as device materials, fabrication techniques, and quality control measures need to be carefully considered to address these challenges.

Clinical validation and commercialization of microfluidic-based biomarker detection devices face regulatory hurdles and require rigorous clinical trials. Meeting regulatory requirements and obtaining necessary approvals can be time-consuming and costly. Additionally, conducting large-scale clinical trials to validate the performance and clinical utility of these devices is essential for their acceptance and adoption in clinical practice.

Market analysis and development of viable business models are crucial for the successful commercialization of microfluidic-based biomarker detection devices. Understanding market dynamics, identifying target markets, and developing sustainable business models are essential for the widespread adoption and commercial success of these technologies.

Looking ahead, several emerging trends and future perspectives can shape the field of microfluidic-based biomarker detection. Integration of artificial intelligence and machine learning algorithms can enhance data analysis and interpretation, leading to more accurate and meaningful insights from biomarker data. Lab-on-a-chip systems that integrate multiple functionalities, such as sample preparation, detection, and data analysis, have the potential to enable personalized medicine by providing rapid and comprehensive diagnostic information.

Furthermore, wearable and implantable microfluidic devices hold promise for continuous monitoring and real-time analysis of biomarkers. These devices can provide valuable information for disease management and personalized treatment strategies. Continued advancements in microfluidic technology, materials, and device design will contribute to the further development and adoption of these emerging trends.

In conclusion, while there are technical challenges to overcome, the future of microfluidic-based biomarker detection is promising. Addressing sample complexity, non-specific binding, and stability issues, along with navigating regulatory hurdles and clinical validation, will pave the way for successful commercialization. Integration of artificial intelligence, lab-on-a-chip systems, and wearable/implantable devices are emerging trends that will shape the future of this field. By addressing these challenges and embracing these trends, microfluidic-based biomarker detection has the potential to revolutionize diagnostics and personalized medicine.

## VIII. Conclusion

In conclusion, microfluidic point-of-care (POC) diagnostics have emerged as a powerful tool for rapid and accurate disease detection and management. The integration of microfluidic systems with various diagnostic techniques, such as nucleic acid amplification and biomarker analysis, has shown great potential in infectious disease diagnostics, chronic disease management, and other applications.

Key findings and contributions in this field include the development of user-friendly interfaces, efficient sample input methods, and the integration of detection and readout systems. Miniaturization strategies have enabled the creation of portable and easy-to-use POC devices. The validation and quality control of these devices ensure their reliability and accuracy.

The impact of microfluidic POC diagnostics on global health is significant. By bringing diagnostics closer to the point of care, these devices enable early detection and timely intervention, leading to improved patient outcomes. The ability to rapidly detect infectious diseases, monitor chronic conditions, and perform other diagnostic tests has the potential to reduce healthcare costs, enhance access to healthcare in remote areas, and contribute to the prevention and control of disease outbreaks.

Looking to the future, research and development in microfluidic POC diagnostics hold great promise. Integration of artificial intelligence and machine learning algorithms can further enhance data analysis and interpretation, leading to more accurate and personalized diagnostics. Lab-on-a-chip systems and wearable/implantable microfluidic devices offer exciting opportunities for continuous monitoring and personalized medicine. Continued advancements in materials, device design, and regulatory frameworks will shape the future of this field.

In conclusion, microfluidic POC diagnostics have the potential to revolutionize healthcare delivery, improve patient outcomes, and contribute to global health. The ongoing research and development in this field will undoubtedly lead to further advancements and innovations, making microfluidic-based diagnostics an indispensable tool in the future of healthcare.

**References**

1. ———. “Recent developments in electroceramics: MEMS applications for energy and environment.” Ceramics International 30, no. 7 (January 1, 2004): 1147–54. https://doi.org/10.1016/j.ceramint.2003.12.012.

2. Chen, Baozhen, Archana Parashar, and Santosh Pandey. “Folded Floating-Gate CMOS Biosensor for the Detection of Charged Biochemical Molecules.” IEEE Sensors Journal 11, no. 11 (November 1, 2011): 2906–10. https://doi.org/10.1109/jsen.2011.2149514.

3. Ratner, Buddy D. “Advances in the analysis of surfaces of biomedical interest.” Surface and Interface Analysis 23, no. 7–8 (July 1, 1995): 521–28. https://doi.org/10.1002/sia.740230712.

4. Pandey, S., A. Bortei-Doku, and M.H. White. “A Novel CMOS Integrated Amplifier for Sensing Single Ion-Channel Current in Biological Cells,” March 10, 2006. https://doi.org/10.1109/isdrs.2005.1596114.

5. ———. “Progress in direct-current plasma immersion ion implantation and recent applications of plasma immersion ion implantation and deposition.” Surface & Coatings Technology/Surface and Coatings Technology 229 (August 1, 2013): 2–11. https://doi.org/10.1016/j.surfcoat.2012.03.073.

6. Chu, Paul K. “Applications of plasma-based technology to microelectronics and biomedical engineering.” Surface & Coatings Technology/Surface and Coatings Technology 203, no. 17–18 (June 1, 2009): 2793–98. https://doi.org/10.1016/j.surfcoat.2009.02.131.

7. Pandey, S., R. Mehrotra, M. Chabalko, A. Bortei-Doku, and M.H. White. “A BioMEMS Platform for Planar Patch-Clamping,” March 10, 2006. https://doi.org/10.1109/isdrs.2005.1596113.

8. Fan, J.Y., X.L. Wu, and Paul K. Chu. “Low-dimensional SiC nanostructures: Fabrication, luminescence, and electrical properties.” Progress in Materials Science/Progress in Materials Science 51, no. 8 (November 1, 2006): 983–1031. https://doi.org/10.1016/j.pmatsci.2006.02.001.

9. Pandey, Santosh. “Analytical Modeling of the Ion Number Fluctuations in Biological Ion Channels.” Journal of Nanoscience and Nanotechnology 12, no. 3 (March 1, 2012): 2489–95. https://doi.org/10.1166/jnn.2012.5771.

10. Allameh, S. M., and W. O. Soboyejo. “Microstructure and Surface Topography Evolution of Ti and Ni Thin Structures.” Materials and Manufacturing Processes 19, no. 5 (October 1, 2004): 883–97. https://doi.org/10.1081/amp-200030590.

11. Pandey, Santosh, Rajiv Mehrotra, Sherri Wykosky, and Marvin H. White. "Characterization of a MEMS BioChip for planar patch-clamp recording." Solid-State Electronics 48, no. 10–11 (October 1, 2004): 2061–66. https://doi.org/10.1016/j.sse.2004.05.072.

12. Goel, Malti. "Recent developments in electroceramics: MEMS applications for energy and environment." Ceramics International 30, no. 7 (January 1, 2004): 1147–54. https://doi.org/10.1016/j.ceramint.2003.12.012.

13. Pandey, S., A. Bortei-Doku, and M.H. White. "Modeling Voltage-gated KcsA Ion Channels as Solid-State Nanodevices," March 10, 2006. https://doi.org/10.1109/isdrs.2005.1595980.

14. Sugioka, Koji, and Ya Cheng. "Femtosecond laser three-dimensional micro- and nanofabrication." Applied Physics Reviews 1, no. 4 (December 1, 2014): 041303. https://doi.org/10.1063/1.4904320.

15. Winokur, Eric S., Akwete S. Bortei-Doku, Santosh K. Pandey, Joseph Mulhern, and Marvin H. White. "A CMOS instrumentation amplifier microchip for patch-clamp experiments in biological cells," November 1, 2007. https://doi.org/10.1109/lssa.2007.4400898.

16. Eyckmans, Wim, and Willy Sansen. "The role of microelectronics in biomedical engineering," January 1, 1993. https://lirias.kuleuven.be/handle/123456789/172954.

17. Pandey, Santosh, Zannatul Ferdous, and Marvin H. White. "Planar MEMS bio-chip for recording ion-channel currents in biological cells." Proceedings of SPIE, the International Society for Optical Engineering/Proceedings of SPIE, October 16, 2003. https://doi.org/10.1117/12.514745.

18. Chen, None Baozhen, None Chengwu Tao, Sumarlin William, and Santosh Pandey. "Biochemical sensing of charged polyelectrolytes with a novel CMOS floating-gate device architecture," May 1, 2008. https://doi.org/10.1109/eit.2008.4554318.

19. Pandey, Santosh, Michelle Daryanani, None Baozhen Chen, and None Chengwu Tao. "Novel neuromorphic CMOS device array for biochemical charge sensing," August 1, 2008. https://doi.org/10.1109/iembs.2008.4649655.

20. Kataria, S., N. Kumar, S. Dash, and A.K. Tyagi. "Tribological and deformation behaviour of titanium coating under different sliding contact conditions." Wear 269, no. 11–12 (October 1, 2010): 797–803. https://doi.org/10.1016/j.wear.2010.08.007.