International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST207653

Nucleic Acid Sensors onto Peptide Nucleic Acid (PNA) Surface

Dr. Srabani Ghosh
MVJ College of Engineering, Near ITPB, Whitefield, Bangalore, Karnataka, India

Article Info
Volume 8, Issue 1
Page Number: 83-93
Publication Issue :
January-February-2021

Article History
Accepted : 01 Jan 2021
Published : 22 Jan 2021

ABSTRACT

A biosensor is defined as "a device that uses specific biochemical signal mediated by isolated enzymes, immunosystems, tissues, organelles or whole cells to detect chemical compounds usually by electrical, thermal or optical signals" [1]. A sensor comprises of at least two basic steps, first, target detection and second, signal transduction. The target detection element can be a suitable chemical compound or biological molecules such as small peptides, proteins, nucleic acids, carbohydrates etc. Ideally, this entity should exhibit high level of affinity and specificity towards the analytes. For example, antibodies are protein-based binding molecules that have long been used for target recognition because they meet most of the above criteria. Signal transduction elements are responsible for converting molecular recognition events into physically detectable signals such as, optical (e.g., fluorescence), chemical, electrochemical, magnetic, thermal or mechanical changes.

Keywords : DNA, PNA, Biosensor, Au(111), AFM

I. INTRODUCTION

Single-stranded DNAs and RNAs are capable of sequence-specific binding via base pair hybridization, and have been proven to be useful for nucleic acid detection [2, 3]. It is possible to evolve single-stranded nucleic acids in test tubes that can bind to a diverse range of analytes beyond DNA and RNA with high affinity and specificity. Such nucleic acids are known as aptamers that have shown great potential as biosensing element [4]. Aptamers exhibit specific three-dimensional structures that are important in target recognition by means of molecular interactions analogous to those operating in antibody–antigen pairs [5, 6].

Nucleic acid immobilization on the sensor surface in surface-based nucleic acid sensors is the most significant initial step that can play a key role in the overall performance of the sensor. Ideally, nucleic acids are to be immobilized onto the solid substrate in such a way that a specific recognition signal can be obtained only if they recognize their target probes via specific hybridization interactions. The experimental setup should be such that the various non-specific interactions are largely cancelled out. Hence, experimental conditions must be adjusted for every application, and a large choice of immobilization support and methods should be considered before the most optimal arrangement can be identified. The

Copyright: © the author(s), publisher and licensee Technoscience Academy. This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited

means of immobilization could include primarily two types, one, covalent binding via one end of the nucleic acid molecule, e.g., binding of 5′-thiol-modified DNA oligonucleotide onto gold surface via gold-sulfur interactions [7], or binding of a 5′-amino-modified DNA oligonucleotide onto an epoxy-modified surface [8], and two, non-covalent binding (e.g., affinity binding based on the strong avidin–biotin system, where nucleic acid is biotinylated at its 5' end and the avidin is attached directly to carbon-based surface [2].

Regarding transduction of the molecular recognition event into an electronic signal, mostly the optical, electrochemical, electrical, mechanical or thermal [9–13] methods are applied in the current nucleic acid sensors. While quite high sensitivity (femto molar to atto molar range) [13, 14] in target detection has been exemplified in optical/electrochemical transduction, another approach for sensitivity enhancement, i.e., by application of synthetic nucleic acid analogues like peptide nucleic acid (PNA) [15] and locked nucleic acid (LNA) [16, 17] probes, which are capable of forming more stable duplexes than the DNA probes, may also be explored. The unique physicochemical nature of the peptidic, non-ionic backbone of PNA has promoted the use of PNA oligomers as capture probes in electrochemical, optoelectronic sensors, and microarray based sensor [10, 18–21].

II. NANOSCALE NUCLEIC ACID SENSORS

In recent times, the emergence of nanoscale technologies has led to the development of nanoscale nucleic acid sensors that are suitable for in vitro measurements using small amounts of sample and/or in vivo intracellular measurements [22–25]. In typical surface-based nanoscale sensor technologies, the large surface area to volume ratio of the sensor unit can assist in addressing a greater number of molecular recognition events occurring on the sensor surface that can result in rapid response, high sensitivity and cost-effective performance of the sensor. Many types of nucleic acid nanosensors have been developed and used in a wide array of biomedical and clinical applications [26, 27]. One example that deals with a miniaturized surface-based nucleic acid sensor is the cantilever array based sensor where the bending motion of microcantilevers or nanocantilevers can be used for real-time monitoring of nucleic acid hybridization events occurring on the cantilever surface, with high sensitivity even at the level of detecting single base mismatches in the target DNA sequences [28]. Another example of surface-based nanosensor could be one that exploits nanoparticles (NPs) as the basic sensor units. Nanoparticles, which are functionalized with nucleic acid sequences, have been used as probes in myriads of DNA detection technologies in the last one decade [29–35]. Amongst different types of nanoparticles, the gold nanoparticles have shown great potential in DNA detection, which is reflected in a number of reports that describe hybridization of target DNA molecules to oligonucleotides immobilized onto gold nanoparticles [36–41].

The basic principle of operation in most of the surface-based nucleic acid nanosensors consists of three main steps: 1) functionalization, i.e., immobilization of the nucleic acid sequences onto suitable regions/positions of the sensor array, 2) target recognition, i.e., bringing the analytes, here target nucleic acid sequences, in contact to the sensor probes, and let hybridization take place, 3) readout, i.e., monitoring the recognition signal as a result of hybridization, using fluorescence readout (as in case of optical transduction), or temperature readout (as in case of thermal transduction), or potential readout (as in case of electrochemical transduction) or resistance readout (as in case of nanomechanical transduction using a piezoresistive cantilever sensor). There can indeed be a number of other types of signal

transduction strategies that can be applied in the nanosensor technologies.

One major aspect of the miniaturized sensors is to retain the ability of multi-analyte detection that allows comprehensive analyses, such as a single instrument for glucose, lactate, and potassium detection. Technical developments in manufacturing enabled the development of miniaturized integrated biosensors for determination of glucose, lactate, and urea in micro samples of undiluted whole blood or plasma [26, 27]. The newest generation of biosensors includes miniaturized multi-analyte immunosensor devices with high-throughput capabilities and more than 1000 individually addressable electrodes per square centimeter. These instruments can detect analytes present in the attomole range. Recently, an impressive number of inventive designs of DNA sensors that can detect the target DNA strands at the femtomole to attomole range have been reported [42–44].

The nanofabrication techniques such as inkjet printing, photolithography etc. have become almost indispensable for functionalizing the sensor surface. The inkjet deposition method has been found to be useful for deposition of thiolated oligonucleotides from aqueous buffer solutions onto the gold surface in DNA microarray applications [45], and even for in situ DNA synthesis on glass substrates [46]. Inkjet dispensing technology has several advantages over conventional syringe pump-based dispensers. First, small droplets of nanolitre to picolitre volume can be dispensed. In addition, because the technique is non-contact, delivery of the droplet to a small specific location is not limited by the mechanical size of the tip. For example, a drop can be delivered into a 2 mm-diameter well simply by ejecting the drop above the well without the tip entering the well. The two most common types of inkjet dispensing technologies are first, piezoelectric dispensing that uses a piezoelectric crystal that is in contact with a glass capillary tube to apply force to the fluid. Applying a voltage across the crystal causes it to deform the wall of the capillary with the subsequent ejection of fluid from the tip of the capillary. This type of inkjet dispensing has been used in the present thesis (see chapter 5). Another type of inkjet dispensing technology couples the high-resolution displacement capabilities of a stepper motor-driven syringe pump with the high-speed actuation of a microsolenoid valve. Photolithography, also termed optical lithography or UV lithography, is a process used in microfabrication to pattern parts of a thin film or the bulk of a substrate [47]. The technique uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical "photoresist", or simply "resist," on the substrate. A series of chemical treatments then either engraves the exposure pattern, i.e. where the sample is deposited, into, or enables deposition of a new material in the desired pattern upon, the material underneath the photo resist. For example, in complex integrated circuits, a modern complementary metal oxide semiconductor (CMOS) wafer will go through the photolithographic cycle up to 50 times for preparing the sample.

III. PEPTIDE NUCLEIC ACID (PNA)

Peptide nucleic acid (PNA) is an artificially synthesized polymer, invented by Peter E. Nielsen (University of Copenhagen), Michael Egholm (University of Copenhagen), Rolf H. Berg (Risø National Lab) and Ole Buchardt (University of Copenhagen) during the 1990s [15]. PNA is a DNA analog in which a 2-aminoethyl-glycine linkage generally replaces the normal phosphodiester backbone (Figure 1).

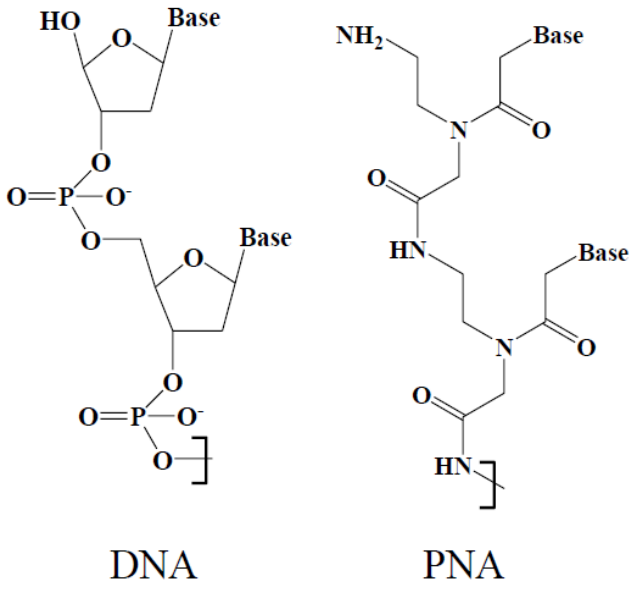

Figure 1 : Chemical structures of Deoxyribonucleic Acid (DNA) and Peptide Nucleic Acid (PNA)

[15, 48]. A methyl carbonyl linker connects natural as well as unusual (in some cases) nucleotide bases to this backbone at the amino nitrogens. PNA is non-ionic, achiral and is not susceptible to hydrolytic (enzymatic) cleavage. PNAs are capable of sequence-specific binding with complementary DNA as well as RNA obeying the Watson-Crick base paring [49, 50]. Its hybrid complexes exhibit extraordinary thermal stability and display unique ionic strength properties. Although PNA was earlier considered to be primarily a potential drug candidate for gene therapy, its other possible uses have been envisaged and/or realized in recent times [51–53]. First, it can be used as a molecular tool in molecular biology and biotechnology [54–58]. For example, PNAs have been designed for developing antigene and anticancer drugs, modulating PCR reactions, detecting genomic mutation or labelling chromosomes in situ [58]. Second, PNA can be used for diagnostics purpose where short PNA probes can be employed as sensor probes [59–62].

The thermal stability of the PNA–DNA/PNA–RNA/PNA–PNA duplexes has been investigated extensively by UV-visible absorption spectrophotometry. The thermal melting temperature (Tm), defined as the temperature at which 50% of the complexes has been dissociated, gives a general idea about the stability of these duplexes. Experiments done with PNA sequences showed that the Tm values are higher for PNA–DNA and PNA–RNA hybrids than for either DNA–DNA or DNA–RNA duplexes. On average, the Tm of a PNA–DNA duplex is 1°C higher per base pair compared to the Tm of the corresponding DNA–DNA or DNA–RNA duplex. Generally a 10-mer PNA–DNA duplex has a Tm of about 50 °C and a 15-mer PNA–DNA duplex has about 70 °C [50, 63]. This observation of increased thermal stability of the PNA hybrids, i.e., PNA–PNA/PNA–RNA/PNA–DNA duplexes compared to the corresponding RNA–DNA/DNA–DNA duplexes could have origin in the non-ionic nature of the PNA backbone, which reduces the destabilizing effect of electrostatic repulsion between the two strands in a duplex. Within the PNA hybrids, the order of the thermal stability of the duplexes is found to be PNA–PNA>PNA–RNA>PNA–DNA [20]. In contrast to the DNA–DNA duplex, the stability of the PNA–DNA hybrids is not significantly affected by changes in ionic strength except in the limit of low ionic strength, i.e., when the salt concentration is few mM, where the stability increases. The binding of PNA to a corresponding complementary DNA oligomer takes place in a sequence-specific manner, which means that the thermal stability of a hetero-duplex, where PNA is one of the components, can be considerably lowered by the presence of imperfect matches. Owing to the high sequence specificity of PNA binding to other nucleic acid strands, incorporation of any mismatch in the duplex considerably affects the Tm value of the hetero-duplex. For example, a single base mismatch results in the lowering of the Tm value by 15 °C and 11 °C in case of the 15 mer PNA–DNA and DNA–DNA duplex,

respectively. This property of PNA is responsible for the remarkable discrimination between perfect matches and mismatches offered by PNA probes, and makes PNA attractive as oligonucleotide recognition elements in biosensor technologies [63].

The PNA strands can form both antiparallel and parallel duplexes with complementary PNA and DNA sequences. While the antiparallel duplexes normally exhibits greater stability compared to the parallel duplexes, the parallel PNA–PNA duplex is still considerably more stable than the corresponding antiparallel DNA–DNA duplex [64]. It has been observed that the Tm values corresponding to antiparallel PNA–PNA, PNA–DNA, and DNA–DNA duplexes follow an order Tm(PNA–PNA) > Tm(PNA–DNA) > Tm(DNA–DNA).

In general, PNA contains an achiral backbone and does not show any circular dichroism (CD) response. However, PNAs with certain modifications of the backbone, e.g., attachment of L-lysinyl amide to the carboxyl terminal of the PNA backbone that leads to a helical structure of all the duplexes that contain PNA as a component [65], are capable of exhibiting CD characteristics. The CD spectra of DNA–DNA duplexes and the antiparallel PNA–DNA and PNA–RNA duplexes appear more or less similar. This suggests that the base pair geometry of antiparallel right-handed PNA containing helices is not much different from that found in a B- or an A-form DNA helix. In contrast, the spectra of parallel PNA–DNA and PNA–RNA duplexes deviate more from the DNA–DNA spectrum, which suggests a different kind of base stacking.

IV. PNA-BASED BIOSENSORS

Application of PNA as a sensor probe in nucleic acid sensor technologies holds great promise for rapid (since formation of PNA-DNA duplex is faster than formation of DNA-DNA duplex) and cost-effective detection (since lesser amount of sample is needed due to high sensitivity in PNA-based measurements) of specific DNA sequences. Usually, single-stranded PNA (ssPNA) probes are immobilized onto the transducer surface by chemical means, e.g., gold-sulfur bond formation for immobilization of thiolated ssPNA probes onto the gold surface. Once the PNA sensor probes can detect the complementary (or non-complementary) target nucleic acid strands in the sample solution, the response from the hybridization event or a lack of it is converted into a useful electronic response by the transducer. Some of the important strategies where PNA has been used as a novel sensor probe for sequence-specific detection of the target nucleic acid strands are described below.

Surface Plasmon Resonance Spectroscopy

The nucleic acid hybridization events and related mismatch analysis can be studied using surface plasmon resonance (SPR) spectroscopy [66]. BIAcore is the company that successfully utilized SPR for real time biomolecular interaction analysis and therefore the method itself is nowadays commonly termed as BIAcore technique [67]. The real-time interactions are monitored on a sensor chip, which constitutes the core part of a BIAcore instrument. The probe molecules are attached directly to the surface of the sensor chip prior to an experiment, the analyte solution is flown in the cell containing the sensor chip, and the recognition events are detected. Surface plasmon resonance arises when light is reflected under certain conditions from a conducting film at the interface between two media of different refractive index - in case of nucleic acid sensing, the conducting film is usually a thin gold coating and the two media are a glass slide (onto which the gold coating is deposited) and the nucleic acid film formed onto the gold coating. SPR causes a reduction in the

intensity of the reflected light at a specific angle of reflection. This angle varies with the refractive index close to the surface on the side opposite from the reflected light (sample side). SPR response values are expressed in resonance units (RU) and one RU is equivalent to 0.0001o.

The first report by Jensen et al. in 1997 on detection of PNA–DNA and PNA–RNA hybridization using SPR showed that the system can differentiate between a complementary and a non-complementary oligonucleotide sequence [20]. The sensor chip used in this case was a thin gold film covered with a layer of dextran and containing streptavidin chemically coupled to the dextran layer. Biotinylated PNA molecules were immobilized on the surface by means of strong coupling between biotin and streptavidin. The amount of bound substance (complementary as well as various non-complementary DNA and RNA oligonucleotides) was measured as a function of time when a solution containing the target strands was flown over the chip surface. In this way, the association kinetics could be studied. The dissociation was subsequently studied by washing the surface with appropriate buffer and monitoring the time dependence of the mass decrease due to removal of the dehybridized target strands from the sensor surface. Assuming a two-state model, A + B □□□ AB, where A and B are reactants, analysis of the hybridization kinetics was carried out. The PNA surface could be regenerated by removing the remaining hybridized products with HCl. Thus, consecutive hybridization events could be detected with the same immobilized PNA layer.

Quartz crystal microbalance (QCM)

The quartz crystal microbalance (QCM) can be used to monitor a change in mass (mass uptake and/or mass loss) deposited on a surface, in form of a change in the resonance frequency of a quartz crystal as a result of the mass change per unit area of the surface. The applications of QCM can be wide-ranging, starting from gas adsorption/desorption to deposition of biomaterials in the monolayer and sub- monolayer regimes. This mass measuring method is applied in the area of biochemistry and biotechnology, such as for studying hybridization of nucleic acids, protein–DNA and protein-protein interaction on the surface [19, 68, 69]. The first report about the study of PNA–DNA hybridization using the QCM biosensor and PNA as the sensor probes comes from the work of Wang et al. [70], which showed that the system could differentiate between complementary and non-complementary oligonucleotides. A fast and sensitive detection of mismatched sequences is possible by monitoring the frequency vs. time response of the PNA-based QCM sensor. The PNA molecules used in the above- mentioned study contained a cysteine attached to the PNA strand with the help of an ethylene glycol unit and a PNA monolayer could be formed onto the gold-coated quartz crystal surface using this thiol-PNA construct [70]. The immobilized PNA probes exhibited remarkable sequence specificity and gave rise to rapid hybridization with the target oligonucleotides sequences. Such level of mismatch sensitivity of the PNA-based QCM sensors can be of great importance for diagnostic applications, particularly for genetic screening and diagnosis of malignant diseases.

MALDI-TOF mass spectrometry

Matrix Assisted Laser Desorption/Ionization (MALDI) – Time-of-Flight (TOF) mass spectrometry (MALDI-TOF-MS) has been used extensively in PNA-based diagnostic research in the last one decade [71–73] to study discrimination of single nucleotide polymorphisms (SNPs) in DNA sequences [74]. PNA-based MALDI-TOF-MS is a strategy that exhibits versatility and rapid analysis capability that are desirable for high throughput genotyping. MALDI-

TOF-MS has evolved into an accurate, sensitive, and rapid method for molecular weight and sequence determination of peptides, proteins and small DNA fragments [74]. This provides a straightforward, rapid and accurate method for specific detection of SNPs in amplified DNA [74, 75]. The detection of multiple point mutations using mass-labeled PNA hybridization probes is also possible by using a direct MALDI-TOF-MS analysis method. In this case, the mass spectra show peaks of distinct masses corresponding to each allele present, and in this way a mass spectral 'fingerprint' of each DNA sample can be obtained.

Electrochemical measurements

The use of PNA as recognition probe for detection of target nucleic acid strand using electrochemical means has been reported as early as in 1996 by Wang et. al. [11]. Their method consisted of four steps: PNA probe immobilization onto the transducer surface (here, a carbon paste electrode), hybridization, indicator binding, and chronopotentiometric transduction. The hybridization experiment was carried out by immersing the electrode into the stirred buffer solution containing a desired target, followed by measurement of signal.

The applications of PNA probes using various strategies as discussed above indicate that it is a novel class of alternative nucleic acid with wide range of biological applications. Their highly specific interactions with DNA and RNA and their chemical and biological stability make them promising both as therapeutic lead compounds and agents for diagnostic applications. PNA has a unique position compared to many other nucleic acid derivatives, and could make an impact, particularly in the establishment of assay procedures for robust routine applications in biosensor technology. Its application as a recognition molecule has already led to promising developments in many areas of chemistry, biology, and biotechnology.

V. REFERENCES

[1]. Biosensors: a clearer view. J. D. Newman, L. J. Tigwell, A. P. F. Turner, P. J. Warner, Cranfield University 2004.

[2]. Electrochemical nucleic acid-based biosensors: concepts, terms, and methodology. J. Labuda, A. M. O. Brett, G. Evtugyn, M. Fojta, M. Mascini, M. Ozsoz, I. Palchetti, E. Palecek, J. Wang, Pure Appl Chem. 2010, 82, 1161–1187.

[3]. DNA based biosensors. J. Zhai, H. Cui, R. Yang, Biotechnol. Adv. 1997, 15, 43–58.

[4]. Nucleic acid-based fluorescent probes and their analytical potential. B. Juskowiak, Anal. Bioanal. Chem. 2011, 399, 3157–3176.

[5]. In vitro selection of RNA molecules that bind specific ligands. A. D. Ellington, J. W. Szostak, Nature 1990, 346, 818–822.

[6]. Systematic evolution of ligands by exponential enrichment: RNA ligands to bacteriophage T4 DNA polymerase. C. Tuerk, L. Gold, Science 1990, 249, 505–510.

[7]. Adsorption of bifunctional organic disulfides on gold surfaces. R. G. Nuzzo, D. L. Allara, J. Am. Chem. Soc. 1983, 105, 4481–4483.

[8]. Direct detection of nucleic acid hybridization on the surface of a charge coupled device. J. B. Lamture, K. L. Beattie, B. E. Burke, M. D. Eggers, D. J. Ehrlich, R. Fowler, M. A. Hollis, B. B. Kosicki, R. K. Reich, S. R. Smith, R. S. Varma, M. E. Hogan, Nucleic Acids Res. 1994, 22, 2121–2125.

[9]. Single nucleotide polymorphism detection by optical DNA-based sensing coupled with whole genomic amplification. M. L. Ermini, S. Mariani, S. Scarano, D. Campa, R. Barale, M. Minunni, Anal. Bioanal. Chem. 2013, 405, 985–993.

[10]. Peptide nucleic acid probes for sequence-specific DNA biosensors. J. Wang, E. Palecek, P. E. Nielsen, G. Rivas, X. Cai, H. Shirashi, N. Dontha, D. Luo, P. A. M. Farias, J. Am. Chem. Soc. 1996, 118, 7667–7670.

[11]. Translating biomolecular recognition into nanomechanics. J. Fritz, M. K. Baller, H. P. Lang, H. Rothuizen, P. Vettiger, E. Meyer, H. J. Güntherodt, C. Gerber, J. K. Gimzewski, Science 2000, 288, 316–318.

[12]. Surface acoustic waves sensor for DNA-biosensor development. N. Fourati, M. Lazerges, C. Vedrine, J. M. Fougnion, C. Zerrouki, L. Rousseau, P. Lepeut, J. J. Bonnet, C. Pernelle, Sensor letters 2009, 7, 1–4.

[13]. Femtomolar electrochemical detection of DNA-targets using metalsulfide nanoparticles. J. Ask, R. Mukhopadhyay, J. O. Hansen, K. Gothelf, J. Am. Chem. Soc. 2006, 128, 3860–3861.

[14]. Attomolar ultrasensitive microRNA detection by DNA-scaffolded silver-nanocluster probe based on isothermal amplification. Y. Q. Liu, M. Zhang, B. C. Yin, B. C. Ye, Anal. Chem. 2012, 84, 5165–5169.

[15]. Sequence selective recognition of DNA by strand displacement with a thymine substituted polyamide. P. E. Nielsen, M. Egholm, R. H. Berg, O. Buchardt, Science 1991, 254, 1497–1500.

[16]. LNA (locked nucleic acids): synthesis and high-affinity nucleic acid recognition. S. K. Singh, P. Nielsen, A. A. Koshkin, J. Wengel, Chem. Commun. 1998, 455–456.

[17]. LNA (Locked Nucleic Acid): An RNA mimic forming exceedingly stable LNA:LNA duplexes. A. A. Koshkin, P. Nielsen, M. Meldgaard, V. K. Rajwanshi, S. K. Singh, J. Wengel, J. Am. Chem. Soc. 1998, 120, 13252–13253.

[18]. Label-free detection of peptide nucleic acid–DNA hybridization using localized surface plasmon resonance based optical biosensor. T. Endo, K. Kerman, N. Nagatani, Y. Takamura, . E. Tamiya, Anal. Chem. 2005, 77, 6976–6984.

[19]. Hybridization of nucleic-acids immobilized on a quartz crystal microbalance. Y. Okahata, Y. Matsunobo, K. Ijiro, M. Mukae, A. Murakami, K. Makino J. Am. Chem. Soc. 1992, 114, 8299–8300. 20Kinetics for hybridization of peptide nucleic acids (PNA) with DNA and RNA studied with the BIAcore technique. K. K. Jensen, H. Orum, P. E. Nielsen, B. Norden, Biochemistry 1997, 36, 5072– 5077.

[20]. Peptide nucleic acids on microarrays and other biosensors. O. Brandt, J. D. Hoheisel, Trends Microbiol. 2004, 22, 617–622.

[21]. DNA-decorated carbon nanotubes for chemical sensing. C. Staii, A. T. Johnson, M. Chen, A. Gelperin, Nano Lett. 2005, 5, 1774–1778.

[22]. Nanosensor for in vivo measurement of the carcinogen benzoa]pyrene in a single cell. P. M. Kasili, B. M. Cullum, G. D. Griffin, T. Vo-Dinh, J. Nanosci. Nanotechnol. 2002, 2, 653–658.

[23]. Sequence-specific label-free DNA sensors Based on silicon nanowires. Z. Li, Y. Chen, X. Li, T. I. Kamins, K. Nauka, R. S. Williams, Nano Lett. 2004, 4, 245–247.

[24]. Fluorescent nanosensors for intracellular chemical analysis: decyl methacrylate liquid polymer matrix and ion-exchange-based potassium PEBBLE sensors with real-time application to viable rat C6 glioma cells. M. Y. Brasuel, R. Kopelman, T. J. Miller, R. Tjalkens, M. A. Philbert, Anal. Chem. 2001, 73, 2221–2228.

[25]. Glucokinase as glucose sensor and metabolic signal generator in pancreatic β-cells and hepatocytes. F. M. Matschinsky, Diabetes 1990, 39, 647–652.

[26]. Oxidase/peroxidase bilayer-modified electrodes as sensors for lactate, pyruvate, cholesterol and uric acid. T. Tatsuma, T. Watanabe, Anal. Chim. Acta 1991, 242, 85–89.

[27]. Micro- and nanocantilever devices and systems for biomolecule detection. K. S. Hwang, S. M. Lee, S. K. Kim, J. H. Lee, T. S. Kim, Annu. Rev. Anal. Chem. 2009, 2, 77–98.

[28]. Design, synthesis and characterization of nucleic-acid functionalized gold surfaces for biomarker detection. N. M. Adams, S. R. Jackson, F. R. Haselton, D. W. Wright, Langmuir 2012, 28, 1068–1082. 30An electrochemical DNA hybridization detection assay based on a silver nanoparticle label. H. Cai, Y. Xu, N. Zhu, P. He, Y. Fang, Analyst 2002, 127, 803–808.

[29]. Nanoparticle-based electrochemical DNA detection. J. Wang, Anal. Chim. Acta 2003, 500, 247–257.

[30]. Selective colorimetric detection of polynucleotides based on the distance-dependent optical properties of gold nanoparticles. R. Elghanian, J. J. Storhoff, R. C. Mucic, R. L. Letsinger, C. A. Mirkin, Science 1997, 277, 1078–1081.

[31]. Array-based electrical detection of DNA with nanoparticle probes. S. J. Park, T. A. Taton, C. A. Mirkin, Science 2002, 295, 1503–1506.

[32]. Gold nanoparticle-based chronocoulometric DNA sensor for amplified detection of DNA. J. Zhang, S. Song, L. Wang, D. Pan, C. A. Fan, Nature protocols 2007, 2, 2888–2895.

[33]. Ultrasensitive DNA detection using oligonucleotide-silver nanoparticle conjugates. D. G. Thompson, A. Enright, K. Faulds, W. E. Smith, D. Graham, Anal. Chem. 2008, 80, 2805–2810.

[34]. One-pot colorimetric differentiation of polynucleotides with single base imperfections using gold nanoparticle probes. J. J. Storhoff, R. Elghanian, R. C. Mucic, C. A. Mirkin, R. L. Letsinger, J. Am. Chem. Soc. 1998, 120, 1959–1964.

[35]. Homogeneous nanoparticle-based quantitative colorimetric detection of oligonucleotides. R. A. Reynolds, C. A. Mirkin, R. L. Letsinger, J. Am. Chem. Soc. 2000, 122, 3795–3796.

[36]. A fluorescence-based method for determining the surface coverage and hybridization effficiency of thiol-capped oligonucleotides bound to gold thin films and nanoparticles. L. M. Demers, C. A. Mirkin, R. C. Mucic, R. A. Reynolds, R. L. Letsinger, R. Elghanian, G. Viswanadham, Anal. Chem. 2000, 72, 5535–5541.

[37]. Defects can increase the melting temperature of DNA–nanoparticle assemblies. N. C. Harris, C. H. Kiang, J. Phys. Chem. B 2006, 110, 16393–16396.

[38]. Melting temperature of surface-tethered DNA. H. Nasef, V. C. Ozalp, V. Beni, C. K. O'Sullivan, C. K. Analytical Biochemistry 2010, 406, 34–40.

[39]. The enhancement effect of gold nanoparticles as a surface modifier on DNA sensor sensitivity. T. Liu, J. Tang, L. Jiang, Biochem. Biophys. Res. Commun. 2004, 313, 3–7.

[40]. Allele-specific genotype detection of factor V leiden mutation from polymerase phain reaction amplicons based on label-free electrochemical genosensor, D. Ozkan, A. Erdem, P. Kara, K. Kerman, B. Meric, J. Hassmann, M. Ozsoz, Anal. Chem. 2002, 74, 5931–5936.

[41]. Electrochemical DNA sensors, T. G. Drummond, M. G. Hill, J. Barton, Nat. Biotechnol. 2003, 21, 11921–1999;

[42]. Attomole DNA electrochemical sensor for the detection of escherichia coli O157. W.C. Liao, J. A. Ho, Anal Chem 2009, 81, 2470–2476.

[43]. Inkjet deposition of alkanethiolate monolayers and DNA oligonucleotides on gold: evaluation of spot uniformity by wet etching. A. Bietsch, M. Hegner, H. P. Lang, Ch. Gerber, Langmuir 2004, 20, 5119–5122.

[44]. http://www.agilent.com/chem/dna.

[45]. Gene expression analysis using oligonucleotide arrays produced by maskless photolithography. E. F. Nuwaysir, W. Huang, T. J. Albert, J. Singh, K. Nuwaysir, A. Pitas, T. Richmond, T. Gorski, J. P. Berg, J. Ballin, M. McCormick, J. Norton, T. Pollock, T. Sumwalt, L. Butcher, D. Porter, M. Molla, C. Hall, F. Blattner, M. R. Sussman, R. L. Wallace, F. Cerrina, R. D. Green, Genome Res. 2002, 12, 1749– 1755.

[46]. Peptide nucleic acids (PNA) – oligonucleotide analogues with an achiral peptide backbone. M. Egholm, O. Buchardt, P. E. Nielsen, R. H. Berg, J. Am. Chem. Soc. 1992, 114, 1895–1897.

[47]. PNA hybridizes to complementary oligonucleotides obeying the Watson-Crick hydrogen bonding rules. M. Egholm, O. Buchardt, L. Christensen, C. Behrens, S. M. Frier, D. A. Driver, R. H. Berg, S. K. Kim, B. Norden, P. E. Nielsen Nature 1993, 365, 566–568.

[48]. Recognition of guanine and adenine in DNA by thymine and cytosine containing peptide nucleic acids. M. Egholm, P. E. Nielsen, O Buchardt, R. H. Berg J. Am. Chem. Soc. 1992, 114, 9677–9678. 51Antisense and antigene properties of peptide nucleic acids. J. C. Hanvey, N. C. Peffer, J. E. Bisi, S. A. Thomson, R. Cadilla, J. A. Josey, D. J. Ricca, C. F. Hassman, M. A. Bonham, K. G. Au, S. G. Carter, D. A. Bruckenstein, A. L. Boyd, S. A. Noble, L. E. Babiss, Science 1992, 258, 1481–1485;

[49]. Peptide nucleic acids (PNA). Potential antisense and antigene agents. P. E. Nielsen, M. Egholm, R. H. Berg, O. Buchardt, Anti-Cancer Drug Design 1993, 8, 53–63.

[50]. Invasion of the CAG triplet repeats by a complementary peptide nucleic acid inhibits transcription of the androgen receptor and TATA binding protein genes and correlates with refolding of an active nucleosome containing a unique AR gene sequence. L. C. Boffa, P. L. Morris, E. M. Carpeneto, M. Louissaint, V. G. Allfrey J. Biol. Chem. 1996, 271, 13228–13233.

[51]. Sequence specific double strand DNA cleavage by peptide nucleic acid (PNA) targeting using nuclease S1. V. Demidov, M. D. Frank-Kamenetskii, M. Egholm, O. Buchardt, P. E. Nielsen, Nucleic Acids Res. 1993, 21, 2103–2107.

[52]. Enhanced PCR amplification of VNTR locus D1S80 using peptide nucleic acid (PNA). D. B. Demers, E. T. Curry, M. Egholm, A. C. Sozer Nucleic Acids Res. 1995, 23, 3050–3055.

[53]. Sequence-specific purification of nucleic acids by PNA-controlled hybrid selection. H. Orum, P. E. Nielsen, M. Jorgensen, C. Larsson, C. Stanley, T. Koch, BioTechniques 1995, 19, 472–480.

[54]. Peptide nucleic acid pre-gel hybridization: an alternative to Southern hybridization. H. Perry-O'Keefe, X. W. Yao, J. M. Coull, M. Fuchs, M. Egholm, Proc. Natl. Acad. Sci. USA 1996, 93, 14670– 14675.

[55]. The peptide nucleic acids (PNAs), powerful tools for molecular genetics and cytogenetics. F. Pellestor, P. Paulasova, Eur J Hum Genet. 2004, 12, 694–700.

[56]. Single base pair mutation analysis by PNA directed PCR clamping. H. Orum, P. E. Nielsen, M. Egholm, R. H. Berg, O. Buchardt, C. Stanley, Nucleic Acids Res. 1993, 21, 5332–5336.

[57]. Screening for genetic mutations. C. Carlsson, M. Jonsson, B. Norden, M. T. Dulay, R. N. Zare, J. Noolandi, P. E. Nielsen, L. C. Tsui, J. Zielenski, Nature 1996, 380, 207.

[58]. Simple and sensitive detection of mutations in the ras proto-oncogenes using PNA-mediated PCR clamping. C. Thiede, E. Bayerdorffer, R. Blasczyk, B. Wittig A. Neubauer, Nucleic Acids Res. 1996, 24, 983–984.

[59]. Direct ultrasensitive electrical detection of DNA and DNA sequence variations using nanowire nanosensors. J. Hahm, C, M. Lieber, Nano Lett. 2004, 4, 51–54.

[60]. DNA biosensors based on Peptide Nucleic Acid (PNA) recognition layers. J. Wang, Biosens. Bioelectron. 1998, 13, 757–762.

[61]. DNA like double helix formed by peptide nucleic acid. P. Wittung, P. E. Nielsen, O. Buchardt, M. Egholm, B. Norden, Nature 1994, 368, 561–563.

[62]. Induced chirality in PNA–PNA duplexes. P. Wittung, M. Eriksson, R. Lyng, P. E. Nielsen, B. Norden, J. Am. Chem. Soc. 1995, 117, 10167–10173.

[63]. Surface Plasmon Resonance Spectroscopy: A Versatile Technique in a Biochemist's Toolbox. R. Bakhtiar, Journal of Chemical Education 2012.

[64]. BIAcore X Instrument Handbook. A. B. Uppsala, Pharmacia Biosensor Sweden 1996, Preliminary Ed.

[65]. Kinetic studies of sequence-specific binding of GCN4- bZIP peptides to DNA strands immobilized on a 27-MHz quartz-crystal microbalance. Y. Okahata, K. Niikura, Y. Sugiura, M. Sawada, T. Morii, Biochemistry 1998, 37, 5666–5672.

[66]. Direct monitoring of DNA polymerase reactions on a quartz-crystal microbalance. K. Niikura, H. Matsuno, Y. Okahata, J. Am. Chem. Soc. 1998, 120, 8537–8538.

[67]. Mismatch-sensitive hybridization detection by peptide nucleic acids immobilized on a quartz-crystal microbalance. J. Wang, P. E. Nielsen, M. Jiang, X. Cai, J. R. Fernandes, D. H. Grant, M. Ozsoz, A. Beglieter, M. Mowat, Anal. Chem. 1997, 69, 5200–5202.

[68]. Peptide nucleic acid characterization by MALDI-TOF mass spectrometry. J. M. Butler, P. Jing- Baucom, M. Huang, P. Belgrader J. Gairard, Anal. Chem. 1996, 68, 3283–3287.

[69]. DNA sequence analysis by MALDI mass spectrometry. F. Kirpekar, E. Nordhoff, K. K. Larsen, K. Kristiansen, P. Roepstorff, F. Hillenkamp, Nucleic Acids Res. 1998, 26, 2554–2559;

[70]. Infrared MALDI mass spectrometry of large nucleic acids. S. Berkenkamp, F. Kirpekar, F. Hillenkamp Science 1998, 281, 260–262.

[71]. Discrimination of single-nucleotide polymorphisms in human DNA using peptide nucleic acid probes detected by MALDI-TOF mass spectrometry. P. L. Ross, K. Lee, P. Belgrader, Anal. Chem. 1997, 69, 4197–4202.

[72]. Spectrometry senses more than a small difference. M. Egholm, Nature Biotechnol. 1997, 15, 1346.

Cite this article as :

Dr. Srabani Ghosh , " Nucleic Acid Sensors onto Peptide Nucleic Acid (PNA) Surface", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 8 Issue 1, pp. 83-93, January-February 2021. Available at doi : https://doi.org/10.32628/IJSRST207653
Journal URL : http://ijsrst.com/IJSRST207653