



UNIVERSITI PUTRA MALAYSIA

***INTERDIGITATED CAPACITOR INCORPORATING CHITOSAN FILM AS
MERCURY METAL ION SENSOR AT MICROWAVE FREQUENCY***

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By

RASHIDAH BINTI RADZALI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfilment of the Requirements for the Degree of Master of Science**

May 2016

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DEDICATION

To my beloved parents Radzali bin Bong & Siti Sawibah Jasin

Brothers and Sisters

Thank You for Everything



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science

INTERDIGITATED CAPACITOR INCORPORATING CHITOSAN FILM AS MERCURY METAL ION SENSOR AT MICROWAVE FREQUENCY

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May 2016

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Various techniques have been used to determine the presence of heavy metal ion. This thesis propose a new finding in a detection of heavy metal ion focusing on mercury metal ion which is by using Interdigitated Capacitor (IDC) and chitosan film as sensor at microwave frequency. This method was chosen because the existing methods to determine the presence of heavy metal ion are complicated and time consuming. IDC sensor incorporating chitosan film will be a novel method as it has never been used to determine the presence of heavy metal ion. The simplicity and cost effective of this project will be a good finding to detect mercury metal ion as well as iron and lead ions.

Resistivity measurement of chitosan film dipped into mercury solution with different temperatures, concentrations and contact time were carried out by using Four-Point Probe. Resistivity of chitosan film increased with increasing concentration and contact time of mercury solution and decreased with increasing temperature. This measurement shows the capability of chitosan to detect the presence of mercury ion by changing in value of resistivity.

IDC sensor was designed and fabricated at frequency range between 130 MHz to 3 GHz. For the microwave measurement, in order to make sure IDC sensor functioning well, the test result for the IDC sensor had been carried out. It shows good agreement with the simulation result and the best sensor has been chosen for microwave measurement.

IDC sensor was then combine with chitosan film and tested for capacitance and transmission (S_{21}) measurement. Chitosan film was dipped into different concentrations of heavy metal ions which are mercury (Hg), lead (Pb) and Iron (Fe). Results show the capacitance increased with increasing concentration for mercury, iron and lead

solution. Transmission (S_{21}) measurement was only carried out for mercury solution and it increased with concentration of mercury solution. Based on the result, this research has proved the capability of IDC sensor incorporating chitosan film to detect the presence of heavy metal ion at 1 ppm to 10 ppm by changing in value of capacitance as well as transmission (S_{21}).



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

**PENGGABUNGAN KAPASITOR INTERDIGITAL DAN FILEM CHITOSAN
SEBAGAI SENSOR ION LOGAM MERKURI PADA FREKUENSI
MIKROGELOMBANG**

Oleh

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Pelbagai teknik telah dijalankan untuk mengesan kehadiran ion logam berat. Kajian ini mencadangkan pengesanan ion logam berat terutama ion logam merkuri menggunakan sensor IDC dan filem chitosan pada frekuensi mikrogelombang. Kaedah ini dipilih kerana kaedah yang sedia ada untuk mengesan kehadiran ion logam merupakan proses yang rumit dan mengambil masa. Penggabungan sensor IDC dan filem chitosan merupakan kaedah yang baru dimana kaedah ini tidak pernah digunakan untuk mengesan kehadiran ion logam berat. Kaedah ini yang mudah dan ekonomi akan menjadi kaedah yang bagus untuk mengkaji kehadiran ion logam berat merkuri serta ion ferum dan ion plumbum.

Kerintangan filem chitosan yang di celup kedalam larutan merkuri dengan kepekatan, suhu dan masa yang berbeza telah dikaji menggunakan Four-Point Probe. Nilai kerintangan filem chitosan menaik dengan naiknya kepekatan dan masa dan menurun dengan naiknya suhu larutan merkuri. Pengukuran ini menunjukkan keupayaan filem chitosan mengesan kehadiran ion logam merkuri.

Sensor IDC telah direka dan di fabrikasi pada frekuensi mikrogelombang di antara 130 MHz hingga 3 GHz. Bagi pengukuran mikrogelombang, untuk memastikan sensor IDC berfungsi dengan baik, IDC sensor telah dikaji dan hasil kajian sensor IDC dipersetujui dengan keputusan simulasi. Sensor yang paling bagus telah dipilih untuk pengukuran mikrogelombang.

Seterusnya, sensor IDC digabungkan bersama filem chitosan dan nilai kapasitor dan penghantaran (S_{21}) telah dikaji. Filem chitosan dicelup kedalam tiga larutan ion logam berat yang berbeza iaitu merkuri (Hg), plumbum (Pb), dan ferum (Fe). Kajian menunjukkan nilai kapasitor menaik apabila kepekatan larutan tinggi. Pengukuran bagi

penghantaran (S_{21}) telah dijalankan bagi ion logam merkuri sahaja dan nilai penghantaran (S_{21}) menaik dengan kepekatan larutan. Kajian ini membuktikan keupayaan sensor IDC bersama filem chitosan untuk mengesan kehadiran ion logam berat pada 1 ppm hingga 10 ppm dengan perbezaan diantara nilai kapasitor dan penghantaran (S_{21}).



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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

IDC	-	Interdigitated Capacitor
MUT	-	Material Under Test
GHz	-	Giga Hertz
dB	-	Decibel
Hg	-	Mercury
Pb	-	Lead
Fe	-	Iron
°C	-	Degree Celcius
S_{21}	-	Transmission
ppm	-	Part Per Million
min	-	Minutes
ϵ_r	-	Relative Permittivity
AAS	-	Atomic Adsorption Spectroscopy
XRF	-	X-Ray Fluorescence Spectrometry
SPR	-	Surface Plasmon Resonance
CVAFS	-	Cold Vapour Atomic Fluorescence Spectrometry
μm	-	Micrometer

CHAPTER 1

INTRODUCTION

Water pollution is recognised as one of the universal problem and has globally drawn the attention of scientist due to the need of clean and vital environment. Cases of heavy metal pollution in water system have been increasingly reported in recent years. A lot of activities such as improper disposal of electric goods, agricultural as well as industrial activities are the main reasons that lead to water pollution.

One of the effects of water pollution is metal ion poisoning. Metal ion poisoning is a deadly problem which may contribute to the neurological dysfunction and cancer. In the United States, the second most abundant water contaminant is mercury as cites by the Environmental Protection Agency (US EPA, n.d.). Based on survey conducted by the Department of Environment Malaysia in 2014, from 876415.44 metric tonnes of schedule waste generated, 12.81 % of it contained heavy metal sludge where it proved that heavy metal pollution has grown to a dangerous level (Malaysia Quality Report, 2014).

Mercury is the 67th most abundant element in the earth and often released into the atmosphere by degassing of the earth's crust. 170, 000 tons of mercury contaminated waste was produced per year by fossil fuel combustion and other activities such as improper waste disposal (Ozuah, 2000). Exposure to mercury may causes loss of myelinated nerve fibers, abnormal central nervous system cell division and autonomic dysfunction. Mercury poisoning also leads to autism and neurodevelopmental syndrome. Several symptoms which are associated with autism are found in mercury poisoning cases such as immune, sensory, neurological motor and behavioural dysfunctions (Bernard *et al.*, 2002).

Although mercury is cited by Environmental Protection Agency in USA as the leading water contaminant, other heavy metals ions such as lead, iron, chromium, arsenic and cadmium can be found abundantly in water supply. Some of these heavy metals are essential to the human body but some of them can cause harm.

Lead poisoning is also one of the most persistent metal contamination issue as it can damaged reproductive system and harmful to the foetus and young children. People who have been exposed to lead for a long time may suffer memory deterioration, prolonged reaction time and reduced ability to understand. In less serious cases, the most obvious sign of lead poisoning is disturbance of haemoglobin synthesis and long-term lead exposure may lead to anaemia (Järup, 2003).

In humans, iron is an essential component but excess of iron can cause toxicity even death. In human poisonings, symptoms of iron intoxication include vomiting, cirrhosis of the liver, coma and abdominal pain (Ahmed & Roy, 2009).

Due to these harmful heavy metals presence in the water system, it is important to implement a sensor system to detect mercury ion as well as any other heavy metals ion in drinking water as heavy metal pollution has been a serious concern to human health.

1.1 Chitosan

Chitin is the second most abundant carbohydrate on earth after cellulose and synthesized by a number of living organisms such as crab and fungi. As chitin is only dissolved in certain solvents, it is often converted into chitosan by alkali treatment which replace the acetyl side group with an amine groups along its backbone (Murray & Dutcher, 2006).

Chitosan is a β -(1 $\rightarrow$ 4)-linked biopolymer of 2-amino-2-deoxy-D-glucose (glucosamine) and it is a linear cationic polysaccharide. Chitosan is non-toxic, biodegradable and occurs naturally in the cell walls of most fungi and some alga (Wan *et al.*, 2003). Chitosan is a material which is soluble in dilute acidic solutions when the percentage of free amine groups along its backbone that is responsible in chelating heavy metal ions is 60 % or higher. The percentage free amine group is called degree of deacetylation (Mcilwee, 2008).

Ability of chitosan to form complexes with transition metals has given rise to the interest from researchers (Guibal *et al.*, 1999). Chitosan gained recognition in water treatment and particularly to recover metal as traces in water system better than any natural compounds due to the free amine groups along its backbone (Rhazi *et al.*, 2002). Chitosan is used in a wide range of applications such as in biotechnology, pharmacists, drugs, food and biosensors (Harish & Tharanathan, 2007).

1.2 Microwave Technique

The applications of microwave technology can be found in various fields from telecommunications, broadcasting, military, environmental remote sensing, medical system, ground positioning system and many more.

Microwave methods for material characterization have two main types which are resonant and non-resonant method. Non resonant methods are often used to investigate the electromagnetic properties over a wide range of frequency while resonant methods

are used to get more accurate dielectric parameter at single or several discrete frequencies.

The fundamental principal behind the two methods is the interaction between propagation waves and medium of which the waves is propagating in materials. There are several forms of such interactions such as reflection, refraction, scattering, emission and adsorption. Microwave sensors are used for various applications. Some of the examples of the microwave sensors are transmission sensors, reflection sensors, resonators and radar sensors.

IDC had been used widely at microwave frequencies due to the fact that it is more effective to measure the capacitance value. Interdigitated capacitors sensor (IDC) is used for the evaluation of near-surface properties such as permeability, conductivity and permittivity of the materials. IDC has been used for measurement of dielectric material for dairy products (Mukhopadhyay *et al.*, 2006) , gas and humidity sensor, biosensor application and also detection of dangerous toxins in contaminated seafood (Radke & Alocilja 2005a; Syaifudin *et al.*, 2009). Application of IDC depends on the characteristic of the sensor itself and also the characteristics of the material under test (MUT). Therefore, there is a possibility to develop IDC sensor for a novel low-cost sensing system for several heavy metal ion which are mercury (Hg), lead (Pb), and iron (Fe).

1.3 Problem Statement

Due to the severe threats that heavy metal pollution poses to human health and environment, it is important to provide a detection system which are low cost, portable, reliable and fast. Several conventional techniques with high sensitivity have been used for heavy metal detection such as atomic adsorption spectroscopy (AAS), x-ray fluorescence spectrometry (XRF), and surface plasmon resonance (SPR) and cold vapour atomic fluorescence spectrometry (CVAFS). All these methods are time consuming, expensive and normally involve complicated processes in order to identify the heavy metal ions from the samples. Hence, sensor which is economical, rapid and has the ability to characterize heavy metal should be prioritized.

This project presents a new technique to detect heavy metal ion by developing a low cost sensor incorporating IDC sensor with chitosan film. Even though chitosan film have been used in conjunction with other detection techniques for heavy metal detection but there is no report on the use of chitosan film with IDC sensor as part of a sensor element. This project will focus on design and characterization of IDC sensor coated with chitosan film for detection of heavy metal ion which are mercury, lead and iron at frequency from 130 MHz to 3 GHz.

1.4 Objectives of the Project

The objectives of this project are

- To design, fabricate and test IDC sensor at microwave frequency
- To determine the presence of heavy metal (mercury, iron, lead) ion focusing on mercury metal ion by using IDC sensor incorporating chitosan film
- To study the effect of different concentration of mercury, lead and iron (1 ppm, 3 ppm, 5 ppm, 7 ppm, 10 ppm) on the capacitance and transmission (S_{21})

1.5 Thesis Outlines

This thesis is structured as follows. Chapter 1 gives a brief introduction on the water pollution and the main problem behind it, followed by chitosan as metal ion binding agent, detection strategies and the problem statement of this project. The previous and current works on chitosan and IDC sensor were covered in Chapter 2. Theory of IDC sensor was explained later in Chapter 3. The methods to prepare chitosan film, technique of detection and sensor fabrication were explained in Chapter 4. The results on the electrical characterization of the chitosan film and the detection of heavy metal ion by using IDC sensor were analysed and discussed in Chapter 5. Lastly, Chapter 6 gives the conclusion and suggestions for future works.

REFERENCES

- Abu-Abed, A. S., & Lindquist, R. G. (2008). Capacitive Interdigital Sensor With Inhomogeneous Nematic Liquid Crystal Film. *Progress In Electromagnetics Research B*, 7, 75–87.
- Ahmed, M. J., & Roy, U. K. (2009). A simple spectrophotometric method for the determination of iron(II) aqueous solutions. *Turkish Journal of Chemistry*, 33, 709–726.
- Alina, M., Azrina, a., Mohd Yunus, a. S., Mohd Zakiuddin, S., Mohd Izuan Effendi, H., & Muhammad Rizal, R. (2012). Heavy metals (mercury, arsenic, cadmium, plumbum) in selected marine fish and shellfish along the straits of malacca. *International Food Research Journal*, 19, 135–140.
- Alley, G. D. (1970). Interdigital Capacitors and Their Application to Lumped-Element {Formatting Citation}Microwave Integrated Circuits. *IEEE Transactions on Microwave Theory and Techniques*, 18, 1028–1033.
- Allouche, F., Guibal, E., & Mameri, N. (2014). Colloids and Surfaces A : Physicochemical and Engineering Aspects Preparation of a new chitosan-based material and its application for mercury sorption, 446, 224–232.
- Angkawisittpan, N., & Manasri, T. (2012). Determination of Sugar Content in Sugar Solutions using Interdigital Capacitor Sensor. *Measurement Science Review*, 12, 8–13.
- Bahl, I. (2003). Lumped Elements For Rf And Microwave Circuit. Phd Proposal. Doi:10.1017/Cbo9781107415324.004
- Bamgbose, J. T., Adewuyi, S., Bamgbose, O., & Adetoye, a a. (2010). Adsorption kinetics of cadmium and lead by chitosan. *Journal of Biotechnology*, 9, 2560–2565.
- Bassi, R., Prasher, S. O., & Simpson, B. K. (2015). Removal of Selected Metal Ions from Aqueous Solutions Using Chitosan Flakes Removal of Selected Metal Ions from Aqueous Solutions Using Chitosan Flakes, 6395. doi:10.1081/SS-100100175
- Bernard, S., Enayati, a, Roger, H., & Binstock, T. (2002). The role of mercury in the pathogenesis of autism. *Molecular Psychiatry*, 7, S42–S43.
- Bhumkar, D. R., & Pokharkar, V. B. (2006). Studies on effect of pH on cross-linking of chitosan with sodium tripolyphosphate: a technical note. *AAPS PharmSciTech*, 7, E50.
- Chetpattananondh, K., Tapoanoi, T., Phukpattaranont, P., & Jindapetch, N. (2014). A self-calibration water level measurement using an interdigital capacitive sensor. *Sensors and Actuators A: Physical*, 209, 175–182.

- Crini, G., & Badot, P. M. (2008). Application of chitosan, a natural aminopolysaccharide, for dye removal from aqueous solutions by adsorption processes using batch studies: A review of recent literature. *Progress in Polymer Science (Oxford)*, 33, 399–447.
- Esfandiari, R., Maki, D. W., & Siracusa, M. (1983). Design of Interdigitated Capacitors and Their Application To Gallium Arsenide Monolithic Filters. *IEEE Transactions on Microwave Theory and Techniques*, MTT-31, 57–64.
- Guibal, E., Milot, C., Eterradosi, O., Gauffier, C., & Domard, A. (1999). Study of molybdate ion sorption on chitosan gel beads by different spectrometric analyses. *International Journal of Biological Macromolecules*, 24, 49–59.
- Harish Prashanth, K. V., & Tharanathan, R. N. (2007). Chitin/chitosan: modifications and their unlimited application potential-an overview. *Trends in Food Science and Technology*, 18, 117–131.
- Hobdell, J. L. (1979). Optimization of interdigital capacitors. *IEEE Transactions on Microwave Theory and Techniques*, 27, 788–791.
- Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68, 167–182.
- Kaminski, W., Tomczak, E., & Jaros, K. (2008). Interactions of metal ions sorbed on chitosan beads. *Desalination*, 218, 281–286.
- Kim, J. W. (2008). Development of Interdigitated Capacitor Sensors for Direct and Wireless Measurements of the Dielectric Properties of Liquids, 115.
- Krajewska, B. (2001). Diffusion of metal ions through gel chitosan membranes. *Reactive and Functional Polymers*, 47, 37–47.
- Laus, R., & De Fevere, V. T. (2011). Competitive adsorption of Cu(II) and Cd(II) ions by chitosan crosslinked with epichlorohydrin-triphosphate. *Bioresource Technology*, 102, 8769–8776.
- Li, N., & Bai, R. (2005). Copper adsorption on chitosan-cellulose hydrogel beads: Behaviors and mechanisms. *Separation and Purification Technology*, 42, 237–247.
- Li, N., Xu, F., Wu, K., Delprat, S., & Chaker, M. (2005). Slow-wave line filter design using full-wave circuit model of interdigital capacitor. *35th European Microwave Conference 2005 - Conference Proceedings*, 1, 409–412.
- Liao, S. Y., Hall, P., & Cliffs, E. (1988). *Microwave Devices and Circuits Third Edition*.
- Lin, S., Chang, C.-C., & Lin, C.-W. (2012). A reversible optical sensor based on chitosan film for the selective detection of copper ions. *Biomedical Engineering: Applications, ...*, 2012, 521612.
- Malaysia Environmental Quality Report 2014, Department of Environment Malaysia 162.

- Mamishhev, A. V., Sundara-Rajan, K., Yang, F., Du, Y., & Zahn, M. (2004). Interdigital sensors and transducers. *Proceedings of the IEEE*, 92, 808–844.
- Manut, a., Zoofakar, a. S., Muhammad, N. a., & Zolkapli, M. (2011). Characterization of Inter Digital capacitor for water level sensor. *2011 IEEE Regional Symposium on Micro and Nanoelectronics, RSM 2011 - Programme and Abstracts*, 359–363.
- McIlwee, H. a, Schauer, C. L., Praig, V. G., Boukherroub, R., & Szunerits, S. (2008). Thin chitosan films as a platform for SPR sensing of ferric ions. *The Analyst*, 133, 673–7.
- Mcilwee, H. A. (2008). *Chitosan Thin Films as Metal Ion Sensors and Structurally Colored Coatings*. Drexel University.
- Mukhopadhyay, S. C., Gooneratne, C. P., Sen Gupta, G., & Demidenko, S. N. (2006). A low-cost sensing system for quality monitoring of dairy products. *IEEE Transactions on Instrumentation and Measurement*, 55, 1331–1338.
- Murray, C. a, & Dutcher, J. R. (2006). Effect of changes in relative humidity and temperature on ultrathin chitosan films. *Biomacromolecules*, 7, 3460–3465.
- Muzzarelli, R. a. a., & Terbojevich, M. (2000). Chitosan. *Handbook of Hydrocolloids*, 472.
- Nayak, A. P., Vj, L., & Islam, M. S. (2011). Wet and Dry Etching, 1–5.
- Ng, J. C. Y., Cheung, W. H., & McKay, G. (2003). Equilibrium studies for the sorption of lead from effluents using chitosan. *Chemosphere*, 52, 1021–1030.
- Ozuah, P. O. (2000). Mercury poisoning. *Current Problems in Pediatrics*, 30, 91–99.
- Sari, E.C., Narsito.,Sri, J.S.,Rudiana,A.,(2010). Adsorption Of Mg (II) Ion From Aqueous Solution, 13, 179–184.
- Qi, L., Xu, Z., Jiang, X., Hu, C., & Zou, X. (2004). Preparation and antibacterial activity of chitosan nanoparticles. *Carbohydrate Research*, 339, 2693–2700.
- Radke, S. M., & Alocilja, E. C. (2004). Design and fabrication of a microimpedance biosensor for bacterial detection. *IEEE Sensors Journal*, 4, 434–440.
- Radke, S. M., & Alocilja, E. C. (2005a). A high density microelectrode array biosensor for detection of E. coli O157:H7. *Biosensors and Bioelectronics*, 20, 1662–1667.
- Radke, S. M., & Alocilja, E. C. (2005b). A microfabricated biosensor for detecting foodborne bioterrorism agents. *IEEE Sensors Journal*, 5, 744–750.
- Rangel-mendez, J. R., Monroy-zepeda, R., Leyva-ramos, E., Diaz-flores, P. E., & Shirai, K. (2009). Chitosan selectivity for removing cadmium (II), copper (II), and lead (II) from aqueous phase : pH and organic matter effect, 162,

503–511.

- Reddy, A. S. G., Eshkeiti, A., Narakathu, B. B., Rebros, M., Rebrosova, E., Joyce, M., & Atashbar, M. Z. (2012). Fully printed wireless LC sensor for heavy metal detection, 1191–1194.
- Rhazi, M., Desbrières, J., Tolaimate, a., Rinaudo, M., Vottero, P., Alagui, a., & El Meray, M. (2002). Influence of the nature of the metal ions on the complexation with chitosan. *European Polymer Journal*, 38, 1523–1530.
- Rinaudo, M. (2006). Chitin and chitosan: Properties and applications. *Progress in Polymer Science*, 31, 603–632.
- Rosu, I., Waveguide, R., Waveguide, R., Line, C., Barrett, R. M., & Cambridge, A. F. (1952). Microstrip , Stripline , and CPW Design. doi:11
- Sadrolhosseini, A. R., Noor, a. S. M., Maksin, M. M., M.Abdi, M., & Mohammadi, A. (2013). Application of Polypyrrole-Chitosan Layer for Detection of Zn (II) and Ni (II) in Aqueous Solutions Using Surface Plasmon Resonance. *International Journal of Polymeric Materials*, 62, 284–287.
- Sağ, Y., & Aktay, Y. (2000). Mass transfer and equilibrium studies for the sorption of chromium ions onto chitin. *Process Biochemistry*, 36, 157–173.
- Sankaramakrishnan, N., Dixit, A., Iyengar, L., & Sanghi, R. (2006). Removal of hexavalent chromium using a novel cross linked xanthated chitosan. *Bioresource Technology*, 97, 2377–2382.
- Shi, L. E., & Tang, Z. X. (2009). Adsorption of nuclease P1 on chitosan nanoparticles. *Brazilian Journal of Chemical Engineering*, 26, 435–443.
- Smits, F. (1958). Measurement of Sheet Resistivities With the 4-Point Probe. *Bell System Technical Journal*, 711–718.
- Stojanović, G., Radovanović, M., Malešev, M., & Radonjanin, V. (2010). Monitoring of Water Content in Building Materials Using a Wireless Passive Sensor. *Sensors*, 10, 4270–4280.
- Syaifudin, a R. M., Jayasundera, K. P., & Mukhopadhyay, S. C. (2009). A low cost novel sensing system for detection of dangerous marine biotoxins in seafood. *Sensors and Actuators B-Chemical*, 137, 67–75.
- Thomas, Bleum. (2001). S-Parameters-Characteristics of Passive Components
- US EPA, O. (n.d.). Mercury in Your Environment.
- Valdes, L. B. (1954). Resistivity Measurements on Germanium for Transistors. *Proceedings of the IRE*, 42, 1429–1434.
- Vieira, R. S., Lisa, M., Oliveira, M., Guibal, E., Rodríguez-castellón, E., & Beppu, M. M. (2011). Colloids and Surfaces A : Physicochemical and Engineering Aspects Copper , mercury and chromium adsorption on natural and crosslinked chitosan films : An XPS investigation of mechanism, 374, 108–

- Vold, I. M. N., Vårum, K. M., Guibal, E., & Smidsrød, O. (2003). Binding of ions to chitosan - Selectivity studies. *Carbohydrate Polymers*, 54, 471–477.
- Vuković Rukavina, A. (2014). Hand-held unit for liquid-type recognition, based on interdigital capacitor. *Measurement*, 51, 289–296.
- Wan Ngah, W. S., Endud, C. S., & Mayanar, R. (2002). Removal of copper(II) ions from aqueous solution onto chitosan and cross-linked chitosan beads. *Reactive and Functional Polymers*, 50, 181–190.
- Wan, Y., Creber, K. a M., Peppley, B., & Bui, V. T. (2003). Synthesis, characterization and ionic conductive properties of phosphorylated chitosan membranes. *Macromolecular Chemistry and Physics*, 204, 850–858.
- Wu, K., & Zhu, L. (1999). Unified Accurate CAD Models for RF, Microwave and Millimeter- Wave Integrated Circuits #, 6–13.
- Xiong, C., Pi, L., Chen, X., Yang, L., Ma, C., & Zheng, X. (2013). Adsorption behavior of Hg^{2+} in aqueous solutions on a novel chelating cross-linked chitosan microsphere. *Carbohydrate Polymers*, 98, 1222–1228.
- Yusof, N. A., & Ahmad, M. (2002). A flow cell optosensor for determination of Co (II) based on immobilised 2- (4-pyridylazo) resorcinol in chitosan membrane by using stopped flow , flow injection analysis, 86, 127–133.
- Zhang, S. (2010). Interdigitated Capacitor Sensor for Complex Dielectric Constant Sensing by.