# Integration of ZnO Nanorod Biosensor with Field-Effect Transistor


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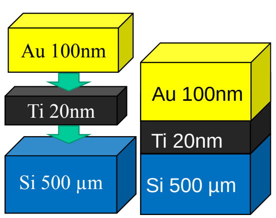
## I. Purpose

Recent technological advances in fabrication of novel hybridized semiconductors, and inorganic nanomaterials may provide the tools necessary to immobilize bio-molecules such as enzyme substrates. The objective of this research is to combine extended-gate field-effect transistors (EG-FETs) with biosensing devices utilizing high aspect ratios of ZnO nanorods (NRs) to achieve a high surface area for glucose immobilization. EG-FETs provide a useful mechanism by aiding in sensitivity, and utilizing energy more efficiently. Diabetes mellitus is a chronic disease which has proven difficult to cure. As of now the best route is precise measurements to manage in keeping blood sugar levels within standard deviation. With diabetes on the rise it is important to develop modern techniques to aid as much as possible.

## II. Methods

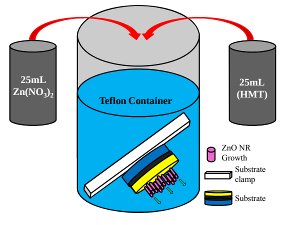
### 1)Electron-Beam Deposition




- The base substrate used in probing of glucose detection is Si(004)
- Si is prepared via cleaving with diamond pen, and organic cleaning
- By means of electron-beam deposition titanium is deposited in a 20nm layer, followed by gold deposition of 100 nm

The Silicon substrate candidacy is based on positive results from prior research at the *Nanomaterials Microdevices Research Center at the Osaka Institute of Technology*. Titanium is added to the silicon substrate as a cost effective diffusion barrier as well as an adhesive for gold to substrate deposition. It should be noted that prior research has shown gold to be an optimal layer for ZnO NRs to be grown on

### 2) ZnO Nanorod Growth



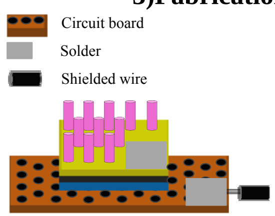

Zinc Nitrate HMT

$Zn(NO_3)_2 \times 6H_2O + C_6N_4H_{12} \rightarrow ZnO + H_2O + 2OH^-$

- (10mM), (30mM), (100mM) 25ml ZnNT solutions prepared
- (10mM), (30mM), (100mM) 25ml Hexamethylenetetramine solutions prepared
- Substrates are fixed via clamp
- Solutions are mixed into Teflon 5 containers
- Substrate is placed as seen in the figure in a nylon container
- Teflon container undergoes microwave radiation for 3hr at 95°C

ZnO NRs have a high aspect ratio which allows optimal immobilization due to a high surface area to volume ratio. The demonstrated ZnO low temperature growth of NRs is a very promising method for integration of biosensors. Previously low temperature, selective growth has been demonstrated.

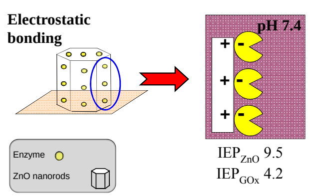
### 3)Fabrication of Biosensor




- Addition of epoxy to the backside of circuit board and solder shielded wire
- Substrate fixed on circuit board with double sided sticky tape, and conductive silver paste added from solder to gold substrate
- Add epoxy everywhere except the top of substrate to prevent exposure to aqueous solutions

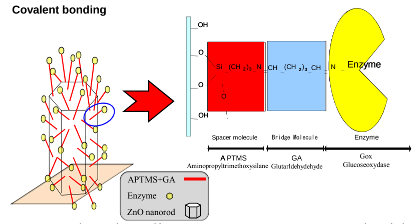
Biosensor fabrication steps stated are to ensure the substrate is in a fixed position, has a connection for parameter analysis, and has a shield against exposure. The solder selected for this experiment was 60% tin 40% lead. Epoxy was a standard commercial hydrophobic material.

### 4)Immobilization of Glucose Enzyme




$IEP_{ZnO}$ 9.5
$IEP_{GOx}$ 4.2

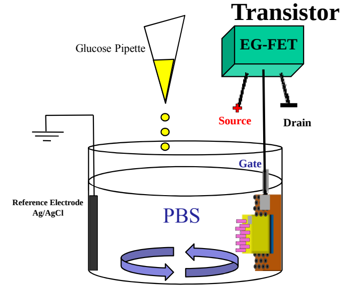
- 15 min for glucose immobilization
- Provides a very quick method
- Less immobilization compared to covalent method
- Bonds are weak compared to covalent method




- Provides many of immobilization enzymes
- Stronger bonds formed
- Process requires 4 steps
- Requires 1 to 3 days for immobilization

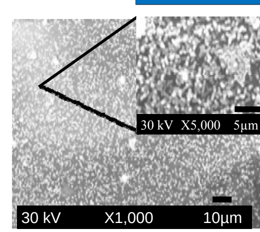
In covalent bonding ZnO NRs are treated with APTMS + toluene aqueous solution. Next the substrate is then transferred to a GA aqueous solution. To complete the covalent bonding process one drop of GOx is applied on the substrate and left for 3 days. In the case of electrostatic bonding one drop of glucose oxidase is applied on the substrate for 15 min. After immobilization a colormetric method was used to check enzyme activity.

### 4)Integration of Extended- Gate Field-Effect Transistor

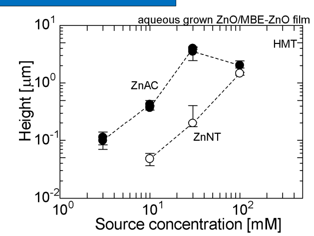



- Biosensor is submerged in solution
- EG-FET is connected to shielded wire
- Electrical baseline is acquired
- Glucose is added and effects in source and drain are measured

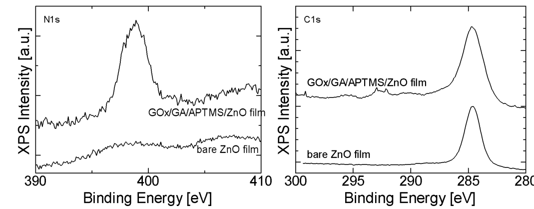
## III. Results



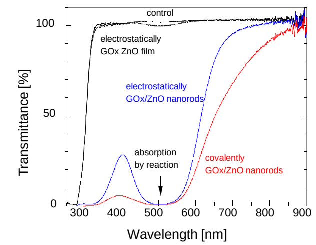

SEM images of ZnO NRs peak on Au/Ti/Si(004) substrate display successful growth in the (0002) axis. The displayed NRs have a average diameter of 400 nm.



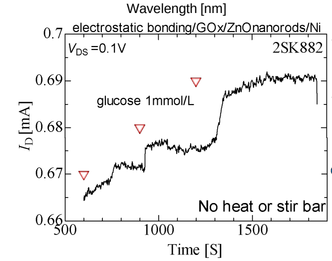

The alpha-step characterization provides a correlation between concentration of precursors and height of NRs. In our parametric trials 100mM equimolar solutions appear to be the best choice.




X-ray photoelectron spectroscopy (XPS) spectra of ZnO NRs/AU/Ti/Si(004) indicate that enzymes have been successfully immobilized. The XPS spectra of N1s, C1s indicates the presence of more nitrogen and carbon in treated substrates with immobilized glucose oxidase.




- Shows difference in immobilization from ZnO film vs NR's surfaces
- Shows difference in electrostatic and covalent bonds
- NRs peak is saturated indicating that more immobilization has taken place




- Glucose sensing is demonstrated
- A relationship exists between current and addition of glucose
- Under 0.1mM of glucose can be detected with optimization

## IV. Conclusions

Low temperature growth of ZnO NRs and integration of EG-FET on Au/Ti/Si(004) substrate was conducted. GOx was immobilized on the high surface area of ZnO NRs and has been characterized by SEM, XPS, and colorimetric measurements. EG-FET will increase current as a result lower quantities of glucose can be detected. Future integration of FET substrate with selectively grown ZnO NRs is next to be investigated.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