



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**DEVELOPMENT OF PORTABLE CERAMIC GAS SENSOR**

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) with Honours.

by

**NURHAFIZA BINTI FADZIL**

**B050810326**

FACULTY OF MANUFACTURING ENGINEERING

2011



## BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

**TAJUK:** Development of Portable Ceramic Gas Sensor

**SESI PENGAJIAN:** 2010/11 Semester 2


Saya **NURHAFIZA BINTI FADZIL**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. \*\*Sila tandakan (✓)


- SULIT** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
- TERHAD** (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
- TIDAK TERHAD**

Disahkan oleh:

  
\_\_\_\_\_

Alamat Tetap:  
NO 58, Persiaran Tmn Melati,  
Tmn Melati. Setapak  
W.P. Kuala Lumpur.

Tarikh: 19/05/2011

  
\_\_\_\_\_

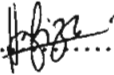
**PENYELIA PSM**  
DR. JARIAH BINTI MOHAMAD JUOI  
Pensyarah Kanan  
Fakulti Kejuruteraan Pembuatan  
Universiti Teknikal Malaysia Melaka

Tarikh: 19/5/2011

\*\* Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

## DECLARATION

I hereby, declared this report entitled “Development of Portable Ceramic Gas Sensor” is the results of my own research except as cited in references.

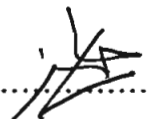
Signature : .....  .....

Author's Name : ..... NURHAFIZA BINTI FAZIL .....

Date : ..... 19 MEI 2011 .....

## APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the Degree in Bachelor of Manufacturing Engineering (Engineering Materials) with Honours. The member of the supervisory committee is as follow:

.....  
  
Supervisor

DR. JARIAH BINTI MUHAMAD JUOI  
Pensyarah Kanan  
Fakulti Kejuruteraan Pembuatan  
Universiti Teknikal Malaysia Melaka

## ABSTRAK

Pengesan gas karbon monoksida daripada motorsikal telah digunakan pada zink oksida, pencantuman zink oksida/kuprum oksida, dan lapis zink oksida/kuprum oksida. Bahan tersebut dihancurkan dengan menggunakan lesung batu *pestle* dan ditapis dengan menggunakan penapis bersaiz 40 $\mu$ m. Saiz zarah bagi serbuk zink oksida dan kuprum oksida ditentukan dengan menggunakan mesin analisa zarah. Kesemua sampel dihasilkan didalam bentuk pil dengan menggunakan mesin *uniaxial dry pressing* pada tekanan 2 tan/cm<sup>3</sup> dan mesin *cold isostatically pressing* pada tekanan 28427.4 psi dan dipanaskan pada suhu 800°C selama 3 jam. Sampel lapisan zink oksida/kuprum oksida pula dihasilkan dengan mengenakan tekanan berturut-turut pada serbuk zink oksida dan kuprum oksida didalam acuan dan dipanaskan pada suhu 800°C pada selama 3 jam. Sampel itu ditambah dengan pengikat seperti *glycerol* dan *stearic acid* untuk menguatkan lagi *green body*. Semasa pemanasan dilakukan, bahan pengikat tadi di bakar keluar pada suhu 295°C untuk *glycerol* dan 388°C untuk *stearic acid* selama 30 minit dengan kadar pemanasan sebanyak 2°C/minit. Pengaruh daripada pemanasan dikaji dengan menggunakan *SEM* dan *XRD*. Respon daripada gas karbon monoksida diukur dengan menggunakan multimeter dan konsenstrasi daripada gas diukur dengan menggunakan alat analisa gas. Kajian diamati bahawa pencantuman zink oksida dan kuprum oksida menunjukkan sensitiviti yang tinggi pada gas karbon monoksida berbanding zink oksida tulen. Gas karbon monoksida akan meningkat dengan meningkatnya kelajuan daripada motosikal dan arus.

## ABSTRACT

Sensing of carbon monoxide (CO) from motorcycle was carried out for pure ZnO, ZnO/CuO heterocontact, and layered ZnO/CuO heterocontact. The materials were crushed using pestle agate mortar and sieved at 40 $\mu$ m mesh. The particle size of powder for ZnO and CuO were observed using particle analyzer machine. All the samples were fabricated in the form of pellet using uniaxial dry pressing for 2 tonnes/cm<sup>3</sup> and cold isostatically press at 28427.4psi and sintering at 800°C for 3 hours. The layered ZnO/CuO samples were fabricated by sequentially pressing ZnO and CuO powders in a die followed by sintering at 800°C for 3 h. The samples were added with binder such as glycerol and stearic acid to provide strength of green body. During sintering, the binder were burn out at 295°C for glycerol and 388°C for stearic acid for 30 minute with heating rate 2°C/ minute. The effect of sintering was characterizing using SEM and XRD. The responses of CO gas were measured using multimeter and concentrations of gas were measured using gas analyzer. The study observed that ZnO/CuO heterocontact showed higher sensitivity to CO gas than pure ZnO. CO gas will increase with increased speed from motorcycle and current.

## **DEDICATION**

To my beloved parents for their boundless love and repeated encouragement

To my family members  
for their wonderful support and concern.

## **ACKNOWLEDGEMENT**

Firstly, I would like to express my sincere gratitude to my supervisor, Dr.Jariah Binti Mohamed Juoi for their guidance, support, comments, and discussions. With their help, this research work has improved tremendously.

My appreciation also goes to the material lab technicians, Encik Sarman, Encik Azhar, Encik Hairul, and also Encik Safarizal for providing me with the necessary equipment to help in this final year project.

A big thank you goes to all my friend seniors and juniors, who have directly and indirectly contributed towards the success of this project. Thank you for making my study of Bachelor Degree at UTeM a memorable and enjoyable one. In truth, only Allah can reciprocate all the kindness. May Allah bless you.



# TABLE OF CONTENTS

Abstrak	i
Abstract	ii
Dedication	iii
Acknowledgement	iv
Table of Contents	v
List of Tables	viii
List of Figures	ix
List of Abbreviations	xi
<b>1. CHAPTER 1</b>	<b>1</b>
1.1 Background of Study	1
1.2 Problem Statement	2
1.3 Objective of Study	3
1.4 Scope of Study	3
1.5 Importance of Research	4
<b>2. CHAPTER 2</b>	<b>5</b>
2.1 Ceramic Materials	5
2.2 Ceramic for Electronics	10
2.3 Ceramic Gas Sensors	12
2.3.1 Semiconductor Gas Sensor	16
2.3.2 Heterocontact Ceramic Sensor	17
2.4 Hazardous Gas of Carbon Monoxide	18
2.5 Ceramic Fabrication Process	20
2.5.1 Forming of Ceramics	20
2.5.2 Additives and Ceramic Forming	22
2.5.2.1 Binder Removal	24
2.5.3 Sintering	24

2.6	Material Characterization	26
2.6.1	Morphological Characterization	26
<b>3.</b>	<b>CHAPTER 3</b>	<b>30</b>
3.1	Introduction	30
3.2	Raw Materials	32
3.3	Experimental Methods	33
3.3.1	Fabrication of ZnO and CuO	33
3.3.2	Fabrication of Layered ZnO-CuO	35
3.3.2.1	Pressureless of layered ZnO and CuO	35
3.3.2.2	Cold Isostatically Pressure of layered ZnO and CuO	36
3.3.3	Preparation of electrical circuit	37
3.3.3.1	Revolution per minute	39
3.4	Characterization Method	40
3.4.1	X-Ray Diffraction (XRD)	41
3.4.2	Scanning Electron Microscope	41
3.4.2.1	Sample preparation	42
<b>4.</b>	<b>CHAPTER 4</b>	<b>43</b>
4.1	Raw Material Characterization	43
4.1.1	Result for Particle Size	43
4.1.2	Discussion of Particle Size	45
4.1.2.1	Particle Size of ZnO	45
4.1.2.2	Particle size of CuO	45
4.2	Sample Preparation	46
4.2.1	Result for Single ZnO	46
4.2.2	Result for Layered ZnO-CuO	46
4.2.3	Discussion of Sample Preparation	48
4.2.3.1	Single ZnO / CuO	48
4.2.3.2	Layered ZnO/CuO	48
4.3	Characterization of Single ZnO, CuO pellet	49

4.3.1	Result for XRD Characterization of ZnO	49
4.3.2	Result for XRD Characterization of CuO	50
4.3.3	Discussion of XRD Characterization	50
4.4	SEM Characterization of Sintered ZnO and CuO	51
4.4.1	Result for SEM Characterization of Sintered ZnO and CuO	51
4.4.2	The effect of Sintering for ZnO and CuO pellet	52
4.5	Response of Carbon Monoxide, CO gas	52
4.5.1	Response of ZnO to CO gas	53
4.5.2	Response of ZnO/CuO heterocontact	53
4.5.3	Discussion of response to CO gas	54
4.5.3.1	ZnO sample	54
4.5.3.2	ZnO/CuO heterocontact sample	54
<b>5. CHAPTER 5</b>		<b>55</b>
5.1	Conclusions	55
5.2	Suggestions	56
<b>REFERENCES</b>		<b>57</b>
<b>APPENDICES</b>		
A	Gantt Chart	
B	Figure of Microstructure	
C	Result Particle Analyzer	
D	Result of XRD	

## LIST OF TABLES

1.1	Global Environment Problems and Related Substances	1
2.1	Application of Advanced Ceramics Classified by Function	6
2.2	Ceramic Materials and their Applications	10
2.3	Example of applications for gas sensors and electronic noses	13
2.4	Types of solid state gas sensors with the corresponding physical change used as gas detection principle (Capone <i>et al</i> , 2003)	15
2.5	Feed Materials and Shapes of the Green Body for the Common Ceramic Forming Methods	22
2.6	Sintering Processes for Some Ceramic Compositions	25
3.1	Chemical properties of Zinc Oxide and Copper Oxide	32
3.2	Chemical properties of Glycerol and Stearic Acid	33
3.3	Lower rpm of motorcycle and higher rpm of motorcycle	39
4.1	ZnO and ZnO/CuO heterocontact sample in air	52
4.2	Result for ZnO sample	53
4.3	Result for ZnO/CuO heterocontact sample	53

## LIST OF FIGURES

2.1	Range of electronic (right-hand side) and ionic (left-hand side) conductivities in $\text{fi}^{-1} \text{cm}^1$ exhibited by ceramics and some of their uses	11
2.2	Ceramic sensors: Properties, Materials and Functions	14
2.3	AutoCAD drawing of the sensor structure, with an interdigitated electrode area of 1.10mm x 0.99 mm, and two electrode contacts located at opposite (Xu.C.J, <i>et.al</i> , 2009)	19
2.4	Granule and pore size change during compaction process (J.S. Reed, 1995)	21
2.5a	Micrographs of unmodified	27
2.5b	Micrographs of CuO-modified (for 15 min)	27
2.5c	CuO-modified (for 60 min) samples	27
2.6a	SEM micrographs of the fractured surface of ZS2	28
2.6b	SEM micrographs of the fractured surface of ZS2A1	28
2.6c	SEM micrographs of the fractured surface of ZS2C1	28
2.7a	SEM micrograph of the ground faces of the dense zinc oxide	29
2.7b	SEM micrograph of the ground faces of the dense copper oxide	29
2.7c	SEM micrograph of the ground faces of the porous zinc oxide	29
2.7d	SEM micrograph of the ground faces of the porous copper oxide	29
3.1	Process Flow Chart for ceramic sensor	31
3.2	Zinc Oxide, Copper Oxide and Stearic Acid	32
3.3	Process flow for fabrication of ZnO and CuO	34
3.4	Sintering process for ZnO and CuO	35
3.5	Flow chart for preparation of layered ZnO-CuO	36
3.6	Sintering process for layered ZnO-CuO	37
3.7a	Schematic diagram for the I-V and the CO gas sensitivity measurement of single-phase ZnO pellets	38
3.7b	Schematic diagram for the I-V and the CO gas sensitivity	38

	measurement of layered- type ZnO-CuO pellets.	
3.8	Sanwa Digital Multimeter Model CD771	38
3.9a	Equipment that have been used for measured rpm at motorcycle - HT-4100 Digital Tachometer	40
3.9b	Tape that used to stick at magnetic coil motorcycle to make the reading of rpm	40
3.10	Process flow for sample preparation before SEM	42
4.1	Range of particle size for ZnO	44
4.2	Range of particle size for CuO	44
4.3a	Layered ZnO-CuO pellet for CIP fully crack to small size	47
4.3b	Layered ZnO-CuO pellet that crack in the middle	47
4.3c	Zinc Oxide and Copper Oxide pellet for single phase	47
4.3d	Layered ZnO-CuO before sintering	47
4.4	Diameter for each sample before sintered	47
4.5	XRD patterns of sintered ZnO ceramic at 800°C	49
4.6	XRD patterns of sintered CuO ceramic at 800°C	50
4.7a	SEM micrograph for sintered ZnO - surface of sintered ZnO samples	51
4.7b	SEM micrograph for sintered ZnO - cross-section in sintered ZnO samples	51
4.7c	SEM micrograph for sintered CuO - surface of sintered CuO samples	51
4.7d	SEM micrograph for sintered CuO - cross-sectional in sintered CuO samples	51

## LIST OF ABBREVIATIONS

Al <sub>2</sub> O <sub>3</sub>	-	Aluminum Oxide
AlN	-	Aluminum Nitride
BaTiO <sub>3</sub>	-	Barium Titanate
BeO	-	Beryllium Oxide
B <sub>4</sub> C	-	Boron Carbide
C	-	Carbon
CIP	-	Cold Isostatically Pressing
CO	-	Carbon Monoxide
CO <sub>2</sub>	-	Carbon dioxide
CH <sub>4</sub>	-	Methane
CuO	-	Copper Oxide
F	-	Fahrenheit
Fe <sub>2</sub> O <sub>3</sub>	-	Iron (III) Oxide
HCl	-	Hydrogen Chloride
H <sub>2</sub> S	-	Hydrogen Sulfide
K	-	Kelvin
MgO	-	Magnesium Oxide
MgCr <sub>2</sub> O <sub>4</sub>	-	Magnesiochromite
MPa	-	Megapascal
N <sub>2</sub> O	-	Nitrous Oxide
NH <sub>3</sub>	-	Ammonia
NO <sub>x</sub>	-	Nitrogen Oxide
O <sub>3</sub>	-	Trioxxygen
PuO <sub>2</sub>	-	Plutonium (IV) Oxide
PLZT	-	Polarized Lead Zirconium Titanate
ppb	-	part per billion
ppm	-	part per million
rpm	-	Revolution per minute

SEM	-	Scanning Electron Microscope
SiC	-	Silicon Carbide
Si <sub>3</sub> N <sub>4</sub>	-	Silicon Nitride
SnO <sub>2</sub>	-	Tin Dioxide
SO <sub>x</sub>	-	Sulfur Dioxide
SrTiO <sub>3</sub>	-	Strontium Titanate
ThO <sub>2</sub>	-	Thorianite
TiO <sub>2</sub>	-	Titanium Dioxide
TiC	-	Titanium Carbide
UO <sub>2</sub>	-	Uranium Dioxide
V <sub>2</sub> O <sub>5</sub>	-	Vanadium (V) Oxide
XRD	-	X-Ray Diffractor
Y <sub>2</sub> O <sub>3</sub>	-	Yttrium Oxide
ZnO	-	Zinc Oxide
ZrO <sub>2</sub>	-	Zirconium Oxide
°C	-	Celsius
μm	-	Micrometer
β-Al <sub>2</sub> O <sub>3</sub>	-	β Aluminium Oxide



# CHAPTER 1

## INTRODUCTION

### 1.1 Background of Study

In recent year, world awareness on environmental problems continues to increase. The continuous release to the atmosphere of chemical pollutants, originating mainly from combustion processes, is the main cause of the deterioration of environmental quality. The development of new methods to air monitor polluted gases in the air is of primary concern for the knowledge of the extension of the environmental deterioration. Measurements of gas concentration in air are being carried out mostly by analytical instruments, which are precise, but also very costly. They often cannot be placed on-site and need long periods for data acquisitions. Table 1 shows the global environmental problems such as acid rain, the green house effect, and ozone layer destruction

**Table 1.1 :** Global Environment Problems and Related Substances

<b>Environmental problems</b>	<b>Related substances</b>
Acid rain	NO <sub>x</sub> , SO <sub>x</sub> , HCl
Greenhouse effect	CO <sub>2</sub> , CH <sub>4</sub> , Fluorocarbon, N <sub>2</sub> O, O <sub>3</sub>
Ozone layer destruction	Fluorocarbon, Hydrocarbon
Offensive odor	H <sub>2</sub> S, NH <sub>3</sub>

Gases are used in many industrial or domestic activities. In the last decade, the specific demand for gas detection and monitoring has emerged particularly as the awareness of the need to protect the environment has grown. There are many types of hazardous gas such as carbon monoxide, sulfur dioxide, hydrogen sulfide, ammonia, methane, nitrogen

dioxide, and many more. With growing the population that the more reliant on automobiles, chemicals, and other potentially hazardous substances, air pollutants can cause major health problems to your health. Some obvious causes of air pollution maybe came from car, but there are many not so obvious products that may use every day that are potentially damaging to healthcare (Fitzpatrick, 2006).

Nowadays, many types of sensors have been developed such as mechanical and electromechanical sensors, thermal sensors, magnetic sensors, radiation sensors, electro analytical sensors, smart sensors, and the latest biosensors. All these sensors are used based on their type. In addition, it also used to detect environmental pollution such as air pollution, noise pollution, light pollution, soil pollution, visual pollution, radioactive contamination and also water pollution.

In this research, function of ceramic sensor is to detect carbon monoxide (CO) gases that are the one of hazardous gases in Malaysia. The type of ceramic material that used for this research is Zinc Oxide (ZnO) and Copper Oxide (CuO). The sensors are going to be produced using powder processing method, sintering, electrical, and testing using XRD and SEM.

## **1.2 Problem Statement**

The detection of hazardous gases is a common need in industrial and domestic environments. The term “hazardous” includes both toxic and combustible gases. Many applications, such as home safety, do not require an exhaustive analysis of the gas, but an alarm level detection (Mandayo, *etc al*, 2002)

Carbon monoxide is one of the hazardous gases. It can found from unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline powered equipment; automobile exhaust from attached garages; and tobacco smoke. The

gas is harmful when breathed because it displaces oxygen in the blood and deprives the heart, brain, and other vital organs of oxygen. Large amounts of CO can overcome in minutes without warning-causing to lose consciousness and suffocate. According to Occupational Safety and Health Administration (2002), besides tightness across the chest, initial symptoms of CO poisoning may include headache, fatigue, dizziness, drowsiness, or nausea. Sudden chest pain may occur in people with angina. During prolonged or high exposures, symptoms may worsen and include vomiting, confusion, and collapse in addition to loss of consciousness and muscle weakness. Symptoms vary widely from person to person. CO poisoning may occur sooner in those most susceptible: young children, elderly people, people with lung or heart disease, people at high altitudes, or those who already have elevated CO blood levels, such as smokers. Also, CO poisoning poses a special risk to fetuses.

### **1.3 Objectives of Study**

The main aim of this research is to develop ceramic gas sensor using compacted of ceramic oxide. This objective is focus on:

- i. To produce ceramic oxide gas sensor.
- ii. To characterize of the sintered ceramic oxide.
- iii. To compare the ZnO/CuO heterocontact sensor with layered ZnO-CuO ceramic sensor.

### **1.4 Scope of Study**

This research was started with preparation of zinc oxide and copper oxide powder. This study is focus on the development of ceramic sensors using oxide powder to detect carbon monoxide gases for preserving the environment.

## **1.5 Importance of Research**

This research will contribute to development ceramic gas sensor for detecting CO gas such as hazardous gases. Material that use for this ceramic sensor is ZnO and CuO. The function of ceramic gas sensor is to detect carbon monoxide. Besides that, it's also used to avoid air pollution. It's because at some concentrations, accidents such as angina, impaired vision, and reduced brain function may result. At higher concentrations, CO exposure can become to fatal.

## **CHAPTER 2**

### **LITERATURE REVIEW**

This chapter discuss on related study based on the previous research conducted by other researchers on development of ceramic sensors. The literature review mainly focused on the theory of ceramic materials and the process of the ceramic sensors.

#### **2.1 Ceramic Materials**

In this research ceramics is the important material to develop a sensor. Ceramic means a combination of covalent, ionic, and sometimes metallic. They consist of arrays of interconnected atoms and there are no discrete molecules. The majority of ceramics are compounds of metals or metal –loids and nonmetals. Most frequently they are oxides, nitrides and carbides. Richerson, (2002) states that “most solid materials that aren’t metal, plastic, or derived from plants or animals are ceramics”. Another that, ceramics also can define for compound of metallic and nonmetallic elements. Ceramic can divided into two parts: traditional ceramics and also advanced ceramics. The applications for these materials are diverse, from bricks and tiles to electronic and magnetic components. For traditional ceramics and glasses, familiar applications include structural building materials (e.g., bricks and roofing tile), refractories for furnace linings, tableware and sanitaryware, electrical insulation (e.g., electrical porcelain and steatite), glass containers, and glasses for building and transportation vehicles. The applications for which advanced ceramics have been developed or proposed very diverse and this area expected to continue to grow at a reasonable rate (Rahaman M.N, 2003). Table 2.1

illustrates some of the applications for advanced ceramics. These applications use the wide range of properties exhibited by ceramics. The functions of ceramics products are dependent on their chemical composition and microstructure, which determines their properties (Carter and Norton, 2007).

**Table 2.1** : Application of Advanced Ceramics Classified by Function (Rahaman, M.N, 2003)

<b>Function</b>	<b>Ceramic</b>	<b>Application</b>
Electric	<p>Insulation materials (Al<sub>2</sub>O<sub>3</sub>, BeO, MgO)</p> <p>Ferroelectric materials (BaTiO<sub>3</sub>, SrTiO<sub>3</sub>)</p> <p>Piezoelectric materials (PZT)</p> <p>Semiconductor materials (BaTiO<sub>3</sub>, SiC, ZnO-Bu<sub>2</sub>O<sub>3</sub>, V<sub>2</sub>O<sub>5</sub> and other transition metal oxides)</p>	<p>Integrated circuit substrate, package, wiring substrate, resistor substrate, electronics interconnection substrate</p> <p>Ceramic capacitor</p> <p>Vibrator, oscillator, filter, etc.</p> <p>Tranducer, ultrasonic humidifier, piezoelectric spark generator, etc.</p> <p>NTC thermistor: temperature sensor, temperature compensation, etc.</p> <p>PTC thermistor: heater element, switch, temperature compensation, etc.</p> <p>CTR thermistor: heat sensor element</p> <p>Thick-film sensor: infrared</p> <p>Varistor : noise elimination, surge current absorber, lightning arrestor, etc.</p> <p>Sintered Cds material: solar cell</p> <p>SiC heater : electric furnace</p>

	<p>Ion-conducting materials (<math>\beta</math>-Al<sub>2</sub>O<sub>3</sub>, ZrO<sub>2</sub>)</p>	<p>heater, miniature heater, etc. Solid electrolyte for sodium battery ZrO<sub>2</sub> ceramics : oxygen sensor, pH meter, fuel cell</p>
<p>Magnetic</p>	<p>Soft ferrite</p> <p>Hard ferrite</p>	<p>Magnetic recording head, temperature sensor, etc. Ferrite magnet, fractional horse power motors, etc.</p>
<p>Optical</p>	<p>Translucent alumina</p> <p>Translucent Mg-Al spinel, mullite, etc.</p> <p>Translucent Y<sub>2</sub>O<sub>3</sub>-ThO<sub>2</sub> ceramics</p> <p>PLZT ceramics</p>	<p>High-pressure sodium vapor lamp</p> <p>Lighting tube, special-purpose lamp, infrared transmission window materials</p> <p>Laser materials</p> <p>Light memory element, video display and storage system, light modulation element, light shutter, light valve</p>
<p>Chemical</p>	<p>Gas sensor (ZnO, Fe<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>)</p> <p>Humidity sensor (MgCr<sub>2</sub>O<sub>4</sub>-TiO<sub>2</sub>)</p> <p>Catalyst carrier (cordierite)</p> <p>Organic catalyst</p> <p>Electrodes (titanates,</p>	<p>Gas leakage alarm, automatic ventilation alarm; hydrocarbon, fluorocarbon detectors, etc.</p> <p>Cooking control element in microwave oven, etc.</p> <p>Catalyst carrier for emission control</p> <p>Enzyme carrier, zeolites</p> <p>Electrowinning aluminium,</p>

	sulfides, borides)	photochemical processes, chlorine production.
Thermal	ZrO <sub>2</sub> , TiO <sub>2</sub>	Infrared radiator
Mechanical	Cutting tools (Al <sub>2</sub> O <sub>3</sub> , TiC, TiN, others)  Wear resistance materials (Al <sub>2</sub> O <sub>3</sub> , ZrO <sub>2</sub> )  Heat resistance materials (SiC, Al <sub>2</sub> O <sub>3</sub> , Si <sub>3</sub> N <sub>4</sub> , others)	Ceramic tool, sintered CBN; cermet tool, artificial diamond; nitride tool  Mechanical seal, ceramic liner, bearings, thread guide, pressure sensors  Ceramic engine, turbine blade, heat exchangers, welding burner nozzle, high frequency combustion crucibles
Biological	Alumina ceramics implantation, hydroxyapatite, bioglass	Artificial tooth root, bone and joint.
Nuclear	UO <sub>2</sub> , UO <sub>2</sub> -PuO <sub>2</sub>  C, SiC, B <sub>4</sub> C  SiC, Al <sub>2</sub> O <sub>3</sub> , C, B <sub>4</sub> C	Nuclear fuels  Cladding materials  Shielding materials

The property of ceramics is further shown by the following observations addressing the six categories of functional properties: (1) thermal chemical, (2) mechanical, (3) thermal conduction, (4) electrical, (5) magnetic, and (6) electromagnetic. Considering mechanical performance, many ceramics have high stiffness and high melting points, reflecting the strong atomic bonding. While stiffness generally decreases with increasing temperature, as for other materials, it is typically an important attribute of many ceramics across the temperature spectrum (Rice R.R, 2003).