Challenges And Opportunities For Manufacturing Chips (Soc) In Ghana

Research Description
Thesis submitted to the Department of Electrical and Electronic Engineering, Kwame Nkrumah University of Science and Technology, Ghana in partial fulfilment of the requirements for the award of the for a degree in BSc. Electrical and Electronic Engineering.

Authors
Adams Abdul-Manan Zakari, Kuwornu-Adjaottor Jethro Otu, Acheampong Emmanuel B.

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TOPIC: CHALLENGES AND OPPORTUNITIES FOR MANUFACTURING CHIPS (SoC) IN GHANA

BY

ADAMS ABDUL-MANAN ZAKARI 5916816
KUWORNU-ADJAOOTTOR JETHRO OTU 5925216
ACHEAMPONG EMMANUEL B. 5916516

SUPERVISOR: MR. GIDEON ADOM-BAMFI

JUNE, 2020
DECLARATION

We hereby declare that this project ‘CHALLENGES AND OPPORTUNITIES FOR MANUFACTURING CHIPS (SoC) IN GHANA’ is our submission as the original work done by us through research and under the supervision of Mr. Gideon Adom-Bamfi for the award of a degree in BSc. Electrical and Electronic Engineering. All sources of information and literature in this work has been referenced.

Adams Abdul-Manan Zakari (Candidate)

Signature: .................................................. Date: ..............................................

Kuwornu-Adjaottor Jethro Otu (Candidate)

Signature: .................................................. Date: ..............................................

Acheampong Emmanuel B. (Candidate)

Signature: .................................................. Date: ..............................................

Certified By

Mr. Gideon Adom-Bamfi (Supervisor)

Signature: .................................................. Date: ..............................................
ACKNOWLEDGEMENTS

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To all our respondents and our friends who directly or indirectly helped us to accomplish this research work, God bless you all.

Our final appreciation goes to the entire department of Electrical/Electronic Engineering for their hard work and right teaching during our four years stay in KNUST. May the good Lord bless and reward all your efforts.
ABSTRACT

Production of Integrated Circuit is key for the socio-economic development of any country. The Integrated Circuit, better known as the semiconductor chip, has unleashed change comparable to the Industrial Revolution by making the computer revolution and the digital age possible. The focus of this project is on the study of the challenges and opportunities of producing chips in Ghana. The study made use of a combination of qualitative and quantitative methods and interviews in collecting data. The study reveals that, inefficient utilization of human resources, insufficient research and development (R&D) initiatives, marketing challenges, inadequate science and technology policies, and financial constraints are collectively hindering the production of chips in Ghana. Furthermore, the study reveals that most students know about Integrated Circuits but have little or no knowledge about the processes involved in producing chips. The study reveals the amount of funding needed to establish a design and fabrication hub in Ghana. Also, the study highlights on some opportunities of setting up a design and fabrication hub in Ghana which is key in building capacity towards Ghana’s economic development.
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CHAPTER ONE

1. INTRODUCTION

1.1. Background

Currently, semiconductors also known as integrated circuits, or just chips, as we generally term them, are critical components of many different types of electronic devices, and are regarded as one of the 20th century’s most important inventions [1]. Chips’ mass production capability, durability and building block approach to circuit design allowed the rapid adoption of standardized ICs instead of discrete transistor designs. ICs are now being used in almost all electronic equipment, thus are the “brains” of all these electronic equipment and have revolutionized the field of electronics. Computers, mobile phones and other electronic appliances are now inextricably part of the structure of modern societies, made possible by small size and low cost of ICs. ICs have two main advantages over discrete circuits: cost and efficiency. The cost is low because the chips, with all their parts, are printed as a photolithography device rather than one transistor at a time. In addition, packaged ICs use significantly less material than discrete circuits. Efficiency is high because the components of the IC switch quickly and because of their small size and proximity consume relatively little power. The main drawback of ICs is the high cost of designing them and manufacturing the photomasks required [2].

The ubiquity of chips partly explains why the ecosystem is global. The intense complexity of business offers a deeper understanding. The non-stop, consumer-driven demand for more and better capabilities, features, reliability and speed requires heavy investment in research and development, design and efficiency, low-cost manufacturing, testing, assembly and packaging and distribution. These same pressures also influence the supporting operations such as the production
of semiconductor manufacturing equipment, development of design software and intellectual property cores and provision of raw materials. Over the years, demands for new chip-based technology innovations have grown even higher: Simple scaling and cost reductions based on Moore’s law will soon no longer be enough to improve device performance. The industry is moving quickly into new areas such as brain-inspired computing, the Internet of Things, energy-efficient sensing, autonomous systems, robotics and artificial intelligence demanding new breakthroughs. A globally interdependent industry that pools the best each participant has to offer provides the best path to the future [3].

There was an integration rate of 40 million to 1 billion transistors per chip in systems between the years of 2014 and 2015. As at the present, the number of transistors per chip in devices has become uncountable and there are difficulties in the manufacture of these chips due to this rapid increase in integration densities [4]. Since we are in a technological age, people tend to use devices with these chips so the challenges associated with their manufacture need to be curbed.

This report describes the challenges associated with the manufacture of chips in Ghana. Some general challenges related to the production of chips include: problems of efficiency, problems of synchronization and problems of power minimization. However, we want to focus on chip design and manufacturing challenges in Africa, especially in Ghana. These challenges include: the availability of clean rooms, the availability of silicon sand processing machines, design issues, environmental issues and so much more to be discussed later.

1.2. Aim

This project mainly aims to make known the challenges involved in chip production in Ghana.
1.3. Objectives

The objectives of this project include;

1. The review of scholarly articles on system on chip (SoC) design and fabrication challenges in various continents.

2. Gathering of relevant information on government policies on electronic technology in Ghana.

3. Gathering of information on amount of funding needed to establish a design and fabrication hub in Ghana.

4. Conduction of survey to find out the level of literacy and awareness on SoC technology in Ghana.

5. Gathering of relevant data on some key parameters that could affect chip production in Ghana.

6. **Accessing** of the various parameters that hinder SoC production in Ghana.
CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

Integrated circuits are in many forms but for this project we will be focusing on the type known as the SoC (System-on-Chip). A SoC is an integrated circuit that integrates all the components of a computer or other electronic system. These components usually (but not always) include a central processing unit, memory, input/output ports and secondary storage - all on a single microchip [5]. This section is meant to review scholarly materials relating to the challenges in manufacturing chips. This literature review will help in determining these challenges across the world and especially in Ghana based on some articles and papers as well as other materials. A total of 11 scholarly materials were reviewed.

2.2. Research and Development Strategies to Fast Advance China’s Semiconductor Industry [6]

The rapid growth of the electronic market and the change from global manufacturing of semiconductors to Asia has driven an unparalleled massive expansion of the semiconductor industry in China. The Chinese government actively supports this growth in making the national microelectronics industry more autonomous, competitive and able to pull the development of other high-tech industries in the country, such as information and communications. To maintain its economic growth and further reduce the gap between the Chinese semiconductor industry and global leaders, China's current strong focus on scientific research and technological development is being put on developing its technology skills and efficiency in production. As Chinese
microelectronics industry integrates into the global industry chain, it faces tremendous challenges and opportunities with its weakest connection, research and development (R&D) ability. Although China has traditionally been less successful in developing an internationally competitive semiconductor industry, the current government initiative is focusing significantly more resources, introducing promotional policies, and creating effective strategies. The key issue that has long hampered the growth of the semiconductor industry in China in the past is that the actions taken have often been arbitrary, duplicative, poorly coordinated and distributed in resources "in all directions." The current government plans for the short-term (the eleventh five-year plan), mid-term and long-term (up to 2020) growth of semiconductor technology in China are strategized for a more oriented and simplified R&D chain by establishing an efficient and effective system for innovation based on cooperation between industries, universities and research institutes. The government strongly encourages the industry to increase its share of national R&D activities and, by working closely with research institutions and universities, to establish an industrial culture that focuses on promoting new technologies for the global market, not just pure research. Significant efforts have been made to exploit and strengthen the R&D expertise of already established businesses as well as to promote new start-ups to fill the critical technology blanks and capitalize on emerging market opportunities. China is investing substantial resources in the semi-conductor manufacturing infrastructure and R&D personnel. Both central and local governments have funded a number of open chip design and chip development technology R&D centers and built numerous high-tech parks to incubate start-ups. There has been considerable effort to attract and retain technical and managerial expertise from overseas. At the same time, educational and training programs have been put in place to boost a large number of local talents to meet the rising needs of microelectronic industry and research institutions for research and development. For example,
in universities across the country, eighteen "IC Talent Cultivation Base" have been developed. Because of a whole set of policies and reforms that have been put in place, China is now planning for a semiconductor technological take-off. Obviously, government's ambitious investments in microelectronic research and development will have a huge impact on China's future semiconductor industry and pave the way from "Made-in-China" to "Created-in-China" [6].

2.3. Selecting Research and Development Center Partners for Semiconductor Industry in Taiwan [7]

This paper describes the process of defining the technologies and partners that are required. Successful economic growth is an updating cycle in which a nation's business environment changes to enable ever more sophisticated and efficient ways to compete. In economic development, the central issue is how to create conditions for fast and sustainable productivity growth. The study shows a mechanism for selecting possible IC industry RDC partners in Taiwan. Using a top-down approach, the process begins by evaluating the nature of the entire IC industry and identifying potential fields; then identifying essential technologies by contrasting world and Taiwan trends; then rating technology based on industry opinions; and finally listing potential candidates based on a 4-factor evaluation. As the list is being produced by business intelligence analysts and industry executives, the result is widely agreed and is considered an important guideline for the RDC policy of Taiwan. While the method indicates some large firms in the region, businesses in the chosen sectors are favored in practice. This is because some partners do not have strong capabilities in the field, but they want to develop capabilities in the field. The procedure in this study is simple and straightforward. Simplicity makes communication with other parties
simple. Nevertheless, the process does not address other important factors, including cooperation with the domestic research institutes or academy [7].

2.4. Basic Information – Background on the U.S Semiconductor Industry Workforce [8]

This paper talks about the challenges and needs of semiconductor industry work force in the U.S. According to the paper some companies have difficulties in finding enough qualified U.S workers with advanced graduate level education, skills and expertise needed to compete in the global economy. This is because, about half of the graduate students studying the physical sciences in U.S universities are foreign nationals and the percentage of them keeps on increasing as the level of degree increases.

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<th>Discipline</th>
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<tr>
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<td>Master’s degree</td>
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<tr>
<td><strong>Computer Science/Information Technology</strong></td>
<td>Nonresident Total 29.231</td>
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<tr>
<td></td>
<td>Percent Foreign Nationals 63.0%</td>
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<td>Total Graduates 46.419</td>
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<tr>
<td><strong>Electrical, Electronics and Communications</strong></td>
<td>Nonresident Total 10.651</td>
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<td><strong>Engineering/ Computer Engineering/Microelectronics</strong></td>
<td>Percent Foreign Nationals 75.0%</td>
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<td>Total Graduates 14.043</td>
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Also, there is the lack of academic programs supporting emerging technologies. Most educational institutions in the U.S are yet to develop curriculum for incoming technologies critical to the future of the semiconductor industry, such as Artificial intelligence. The absence of these programs to support the training of skilled personnel contributes to the absence of these skilled personnel. Due to this, new recruits of the semiconductor industry often lack specific skills and the broader set of “soft skills” needed for effective work in the industry [8].

2.5. Software in the Semiconductor Industry [9]

Today there is a restructuring of the semiconductor industry. Technology plays a more important role because consumers are opting for systems (embedded systems) instead of chips. A few years ago, customers from the semiconductor industry bought chips to use those chips to design systems. It must change the design of embedded systems and/or products manufactured by the semiconductor industry. It must be adapted to this new requirement of the industry. The following sections explain today's most common design approach and the issues associated with this technique. This paper presents a different design approach for embedded systems. This design approach takes into account the business demands of today's semiconductor, as well as the fact that software is an integral part of today's semiconductor industry's systems. The four product
characteristics (speed, size, functionality, and cost) expected by the consumer are easier to achieve using the design approach outlined in this paper. The production flow also guarantees that the product arrives on the market in a timely manner and is not late due to design issues [9].

2.6. Semiconductor Financing [10]

The semiconductor industry has gradually evolved into a mature industry after witnessing strong growth for several decades. The global market is expected to rise at just 0.3 percent next year to hit a size of $341 billion, compared to a compounded annual growth rate of 7.6 percent between 1990 and 2015. At the same time, there has been a substantial increase in the amount of capital and time needed to fund a start-up semiconductor business through profitability. Such factors make access to capital more difficult to fund new innovations, and in the coming decades the industry will need new funding mechanisms to promote innovation. Historically, Venture Capitalists ("VC's") have supported innovation and development beyond major corporate R&D functions. This provided an opportunity for entrepreneurs to pursue new ideas, develop new technology, and create new businesses. Given many public semiconductor companies’ attractive results, there are challenges for smaller firms. There are increased reporting requirements and demands for quarterly earnings as well as perceived investor pressure to display growth, good operations and efficient capital structures to improve shareholder returns [10].
2.7. The Adoption of Application-Specific IC Technology by the UK Manufacturing Base [11]

Despite ongoing marketing by semiconductor firms, retailers, and design houses, the UK's adoption of application-specific integrated circuit (ASIC) technology continues to lag behind its leading competitor nations. The application-specific integrated circuits (ASICs) are lightweight, cheap and easy to build, but not many people use them. This is the result of recent research on ASIC manufacturing in the United Kingdom. In response to a survey conducted by the author, it indicates the likely size of the UK masked ASIC market by design starting from the expectations of the supply industry. Masked ASICs are systems that are programmed by the manufacturer of semiconductors rather than allowing the consumer to perform a subsequent programming step. Since embracing ASIC technology, the UK has been sluggish and is slipping behind its rival nations. The reasons for this are many and nuanced, but are largely based on future consumers' misunderstanding of the technology, which is not supported by the majority of the supply industry. Obviously, this situation can have a significant impact on governance and education [11].


Innovation is leading the path to achieving competitive advantage in the microelectronics industry. So, today's spending in R&D is the way to remain competitive in the market tomorrow. Previously, with strong assistance from international MNCs, Malaysia laid the groundwork for R&D foundation. Nevertheless, as foreign MNCs come and go, particularly with the prospect of a better investment site elsewhere, the engine for Malaysia's R&D cannot be relied on continuously. The
forging of an alliance with eMNCs, as stated in the previous section, provides access to cutting-edge technologies. Malaysia, however, cannot not only on the new wafer manufacturing methodologies, but also on their upstream and downstream activities in the industry, such as front-end wafer design. In Malaysia, the government will recognize these activities and encourage their growth. Malaysia needs to develop indigenous R&D capabilities in order to continue the current evolution of the electronics industry and to enter the next level of technical development. Malaysia's current challenge is the scarcity of scientists and engineers. Malaysia has only about 400 compared to 4,000 to 6,000 scientists per million people in developed countries. In order to overcome this issue, Malaysia's universities and colleges are now preparing to produce in the near future about 20,000 degree and diploma holder, half of whom come from scientific and technical disciplines [12].

Release control plays a major role in the efficiency of a wafer manufacturing facility for semiconductors. Over the past decades, the semiconductor industry has become one of the focal points of global industrial growth. Most countries have been involved in every aspect of this industry. In addition, the manufacture of semiconductors is generally recognized as one of the most complicated manufacturing processes. Reentrancy of lots (i.e. jobs) and unbalanced production facilities are typically two of the most important and special features in the manufacture of semiconductors. This paper introduced some specific policies for release control and provided them with a comparison of results [13].
2.9.1. Common Release Control Policies

The release strategy is a requirement for a semiconductor wafer fabrication facility to run smoothly. It is generally possible to divide the release strategy into static and dynamic ones. Common release control policies are induced as follows. Wherein, FIFO and EDD are static release control policies; CONWIP, SA, WIPCTRL and WR are dynamic ones. Some of these policies are explained below.

2.9.2. FIFO

FIFO determines the time and number of lots to be released according to their arriving sequence. It is the simplest policy without consideration about the properties of products and real-time status information of production lines.

2.9.3. EDD

EDD takes the deliveries of products into consideration. EDD firstly sorts the products according to their deliveries in ascending order, then releases them according to the sorted sequence. EDD takes the deliveries of products into account, but real-time status information is not considered.

2.9.4. CONWIP

In CONWIP release policy, a new lot is released into the fab whenever a lot is completed in a fab. In other words, whenever the number of lots in the fab drops below a constant WIP level, a new lot is released into the fab. The constant WIP level is determined empirically. Thus, the release time of the lots depends on the current WIP level. CONWIP is able to adapt the changing product varieties with strong robustness.
2.9.5. **WIPCTRL**

WIPCTRL is a workload limited release methodology for overall shop floor. WIPLOAD is defined as the sum of the remaining processing times of all the jobs in the fab. A new lot is released when the WIPLOAD falls below a critical value. The critical value is set by simulations. This policy is able to smooth out the fluctuations of the workload [13].

2.10. **Semiconductor Integrated Circuit Packaging Technology Challenges - Next Five Years** [14]

This paper will address many of the IC packaging technology challenges that need to be addressed during the next five years. This paper talks about the availability of new packaging materials. Due to the high demand of integrated circuits devices, designers and manufacturers are trying to minimize the sizes of these ICs in order to incorporate a lot of them in a single device to promote multi-tasking. However, materials to be used in this miniaturization process are not common in most chip manufacturing industries. An example of such material is the low stress under fill which is used to support the cut ICs during the miniaturization process. All these materials to be used involve cost which is also an issue. The paper also talks about the issue of scaling. Since devices are now becoming portable, there is a need for chips to also reduce in size. However, the process of scaling is a problem since the interconnects of the smaller chip, thus the I/O ports, will also have to be made small and will need to have a performance greater than or equal to that of the larger chip that has been scaled. Most chip producing industries lack the technologies for these scaling processes as a result of the availably and cost [14].
2.11. **Challenges for Future Soc Design** [15]

This paper was aimed at talking about design issues of generality, heterogeneity as well as testing. Generality refers to the re-usability of design components. It is usually prominent in the IP based design of chips. Generality is a method used to reduce design-effort and also save time. Due to the increase in product complexity, generality becomes a problem. Since chips are now designed to perform different tasks nowadays, hence require different components, the re-usability of the design components introduce problems such as security issues, quality issues and integration issues.

The state of diversity is heterogeneity. According to this paper, of the fundamental challenges for SoC design is the heterogeneity of the combined components, and this has an influence on the design and validation. Chips are designed for different purposes and, as a result, different components are integrated that distinguish chip performing a specific task from another chip performing another task. This then makes it difficult to select the different components of the chip as it may not be unique to the task it will perform. In addition to the complexity of the task there is the cost issue. This is a very important issue because there will be no available components without the money needed to produce the specific chip design.

According to this paper, complexity in chips poses testing problems in such a way that, different chip designs to be used for different purposes now have to be integrated to form a single chip design. Therefore, instead of these chip designs to be tested individually, thus the use of the divide-and-conquer scheme, they will have to be tested as a single chip, thus as part of an overall system. This means the traditional scheme of testing cannot be applied on the new complex chip. Beside the increased complexity, the difficulty of testing is also as a result of the heterogeneous nature of chips. Basically, a SoC includes microprocessor cores, logical blocks and memory structures.
These components are traditionally tested as separate chips. Now all these components must be tested as a single chip usually by a super tester. This super tester is able to test the various components one-by-one even though they are integrated on to one single chip but is very expensive. Also, multiple testers can be used but their principle of operation is very time consuming. These testing problems discussed can be solved by the implementation of built-in self-test (BIST) strategy [15].

2.12. Challenges to Manufacturing Submicron, Ultra Large-Scale Integrated Circuits [16]

This paper talks about issues involving the complexity and testing of ICs as well as the budget issues involved in the manufacturing of these chips. Complexity affects a layout engineer’s ability to place millions of transistors on a chip, interconnect them, simulate their functions and finally test them. A layout draftsman working on a microprocessor could design 10 transistor chips per day. At this rate, it would take 500 years for a single draftsman to design 1.2 million transistor chip such as the intel i486™ CPU. The complexity of developing test programs to perform functional testing of VLSI chips has been proven difficult. A logic chip may need thousands of lines of code to run a test machine, taking up to six months of developing and debugging. Recently, MCNC has built a program to read the system of a device and automatically reconfigure the tester to conduct the required testing. This has reduced test development time for ICs to under one day, though the issue still persists in some semiconductor industries.

Successful completion of the manufacturing of chips depends on the ability to maintain tight tolerance budgets and also reliable low costs. Budget issues are associated with costs. These costs are also associated with machinery, the availability of low-particulate clean rooms and other
resources needed for chip manufacturing. Additional costs include the minimization of contamination gases and chemicals. All these requirements need a lot of money to be implemented [16].
CHAPTER THREE

3. METHODOLOGY

3.1. Design of Case Study

A set of online questionnaires was administered to capture very vital information about the awareness and literacy level of Ghanaian students on Integrated Circuits. Students involved in this survey were mainly university students from the various universities in the country.

3.2. Design of Questionnaires

In designing the questionnaire, certain factors were considered in checking the awareness and literacy level of students on integrated circuits design and fabrication in the country:

i. **Basic knowledge on Integrated Circuits:** This involves paying attention to whether students had an idea on what integrated circuits are, their types and basic operations, thus if they knew what they were.

ii. **Technical Feasibility:** Here, the idea of existence of integrated circuits designing and manufacturing companies in the country were taken into consideration.

iii. **Basic Requirements:** Raw materials as well as financial requirements involved in integrated circuit designing and manufacturing were considered.

iv. **Benefit to customer and producer:** This factor highlights how much will be required to establish integrated circuits design and fabrication hubs in the country instead of importing them. Also, attention is paid to the fact that consumers will buy these integrated circuit components and devices made in the country at less prices compared to the high prices of products from other countries.
3.3. Questions on Basic Knowledge

i. **Classification of Integrated Circuits:** Various types of integrated circuits and integrated circuit-based devices known.

ii. **Operation:** Principle of operation of the various types of integrated circuits and integrated circuit-based devices known.

3.4. Production Questions

i. **Availability of Raw materials:** This answers the question, “Does Ghana have the raw materials required in the manufacturing of integrated circuits?”.

ii. **Availability of Human Resources:** This answers the question, “Does Ghana have the human resources, thus, qualified personnel needed in the design and manufacturing of integrated circuits?”.

iii. **Availability of Capital Resources:** This answers the question, “Does Ghana have the necessary equipment needed in the manufacturing of integrated circuits?”.

iv. **Availability of Financial Resources:** Here, cost of establishing integrated circuit design and manufacturing centers is taken into consideration and is meant to answer the question, “Does Ghana have the financial requirements needed to establish design and fabrication hubs?”.

3.5. Marketing and Application Questions

i. **Cost/Price:** This involves questions based on whether customers can afford the integrated circuits produced in Ghana if integrated circuits design and fabrication hubs are established.

ii. **Profitability:** This aims to check whether there will be a loss or gain in investments made to manufacture integrated circuits industries as well as the chips themselves.
CHAPTER FOUR

4. DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESPONSES

4.1. Data Presentation and Analysis

4.1.1. Data from Students

Out of the whole student body, it was practically possible to question a sample size of 100 (Most from College of Sciences and College of Engineering). These two colleges were chosen for the study because some of the departments deal with electronics components for instance Department of Electrical and Electronic Engineering, Telecommunication Engineering, Mechanical Engineering, Physics and Computer Science.

4.1.2. Students’ Responses to Questionnaire

1. a. Do you know what an Integrated Circuit (chip) is?

100 responses

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<tr>
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<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>52</td>
<td>48</td>
</tr>
<tr>
<td>100%</td>
<td>52%</td>
<td>48%</td>
</tr>
</tbody>
</table>

*Figure 4.1 Student's Awareness on Integrated Circuit*
2. a. Do you know of any chip manufacturing company in Ghana?
100 responses

Yes: 8 (9%)
No: 92 (92%)

Figure 4.2 Chip Manufacturing Company in Ghana

3. Do you use any chip-based device or gadget?
100 responses

Yes: 83 (83%)
No: 17 (17%)

Figure 4.3 Chip-based device usage in Ghana
6. Are you familiar with the processes of integrated circuits (chips) in electronic devices?

100 responses

<table>
<thead>
<tr>
<th>Yes</th>
<th>37 (37%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>63 (63%)</td>
</tr>
</tbody>
</table>

Figure 4.4 Awareness of the Processes of Integrated Circuits

7. a. Does Ghana have the raw materials needed to produce silicon?

100 responses

<table>
<thead>
<tr>
<th>Yes</th>
<th>44 (44%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>56 (56%)</td>
</tr>
</tbody>
</table>

Figure 4.5 Students' view on the effect of raw materials on the production of chips
8. a. Do you think Ghana has the financial resources for the manufacturing of chips?

100 responses

Yes: 41 (41%)
No: 59 (59%)

Figure 4.6 Students' view on the effect of finance on the production of chips

11. a. Does Ghana have the human resources needed in the production of chips?

99 responses

Yes: 57 (57.6%)
No: 43 (43.4%)

Figure 4.7 Students' view on the effect of human resources on the production of chips
4.1.3. Analysis of Data from KNUST Students

Figure 4.1 shows that out of one hundred students questioned, 52 students have a brief knowledge of Integrated circuits whilst 48 are do not know about Integrated circuits. The students who knew had the knowledge about Integrated Circuits in their various fields of study.

Figure 4.2 shows that out of one hundred students questioned, only 8 know any chip manufacturing company in Ghana. Analyzing the responses, most of those who knew any manufacturing company actually stated various hubs and centers for fabrication of Printed Circuit Board (PCB) when asked to name the companies for manufacturing Integrated Circuits.

Figure 4.3 shows that out of one hundred students questioned, 83 use chip-based device. Analyzing the responses, most of those who chose NO had no knowledge of what Integrated Circuit is.

Figure 4.4 shows that out of one hundred students questioned, majority that is 63 students do not know the processes involved in producing Integrated Circuit. The students who knew basically had knowledge of the processes from the internet and also in their various fields of study.

Figure 4.5 shows that out of one hundred students questioned, 44 are of the view that Ghana does have the raw materials needed to produce silicon and 56 do not support this view. Further questions were asked to know why Ghana does not produce silicon if we have the raw materials. Below are some reasons the students stated;

- The country lacks technological machines to produce it.
- Lack of technical know-how in the production process.
- Venture capitalist do not find it lucrative to produce silicon in Ghana and Ghana does not have the prospective market for it.
- Poor leadership and lack of managerial skills.
Figure 4.6 shows that out of one hundred students questioned, 41 students hold the view that Ghana has the financial resources for the manufacturing of chips and majority that is 59 students think Ghana does not have the financial capabilities. Again, when a question was asked to justify if they think Ghana has the financial resources for the manufacturing of chips, various reasons were stated and below are some of them;

- Ghana has a lot of resources that give the country income and this income can be channeled into the production of chips.
- The Government can invest in this sector which in the near future will generate a good revenue for the government since these products are in very high demand.
- Through proper management and economics, capital can be raised to support chip production in Ghana.

Figure 4.7 shows that out of one hundred students questioned, 57 students hold the view that Ghana has the requisite human resources for the manufacturing of chips and 43 students think Ghana does not have the needed human resources for the manufacturing of chips. Further questions were asked to those who gave a positive response to know why Ghana does not produce chips if we have the human resources. Below are some reasons the students stated;

- There are competent Computer and Electrical Engineers in the country who can take up this project.
- The country has numerous research facilities and numerous technological universities and institutes. These facilities can help in the production of chips in Ghana.
- Various hubs and Printed Circuit Board (PCB) fabrication centers can help in the design and fabrication of chips in Ghana.
• The country has a youthful population.

4.2. **Discussion of Responses**

4.2.1. **Introduction**

This subchapter presents the discussion of responses of the administered questionnaires. The results of the research are discussed under five main headings:

• What an integrated circuit is, thus, general knowledge and awareness.
• The various integrated circuits companies known by university students.
• The frequency of usage of integrated circuit-based devices by students.
• Students’ awareness on the availability of resources needed for integrated circuits manufacturing.
• Number of years required to establish an integrated circuit industry.

4.2.2. **What is an Integrated Circuit?**

An integrated circuit is a set of electronic circuits on one small flat piece of semiconductor material that is normally silicon. As mentioned earlier in chapter one, they are the brains of almost all electronic equipment. They have both input and output characteristics which enables them to perform multiple computing functions [17]. Per the survey conducted, most of the students knew what an integrated circuit was, thus, from figure 2, about fifty-two percent (52%) of the students knew what an integrated circuit was and the remaining forty-eight percent (48%) had no or little idea about what integrated circuits were. Though most of the students knew what integrated circuits were, most had no idea about the working principles. Only thirty-seven (37%) percent of the knew the principle of operation of an integrated circuit and the remaining sixty-three percent
(63%) had no idea. This can be verified from figure 5. This is probably due to the inadequate exposure of students to the semiconductor world.

4.2.3. Integrated Circuit Companies

There are various integrated circuit companies in the world. Some of them include Intel, Texas Instruments, Skyworks Solutions and Allied Electronics. Most of these companies are suppliers in the USA as well as suppliers internationally [18]. However, there are no semiconductor or integrated circuit companies in Ghana. Technological hubs are the only companies that assume the role of integrated circuit companies in Ghana though they are not able to manufacture the chips. They rather import components of integrated circuits from other countries and assemble them. Kumasi Hive and Invent Electronics are the most popular in the country. According to the survey (figure 3), only eight percent (8%) claimed to know of some integrated circuit companies in Ghana and the remaining ninety-two percent (92%) did not. Those who claimed to know some integrated circuit companies in Ghana ended up mentioning Techno, Infinix, Vodafone and MTN as companies which is not accurate.

4.2.4. Usage of Integrated Circuit-Based Devices

Almost all electronic equipment used nowadays contain integrated circuits. Mobile phones, laptops, tablets and televisions all contain integrated circuits. According to the survey, almost all the students, thus eighty-three percent (83%) of them use chip-based devices whilst the remaining seventeen percent (17%) do not. Per the replies (figure 4), it can be said that the seventeen percent (17%) that claimed they do not used chip-based devices do not know what integrated circuits are. The remaining eighty-three percent (83%) who use chip-based devices went on to comment on how these devices has impacted their lives positively.
4.2.5. Availability of Resources

Figure 6 brings to the realization that Ghana does not have the requisite raw needed to produce silicon because there are various factors that hinders the production of silicon in Ghana. Ghana lacks the technological machines needed to process sand to silicon. Issues of sustainability of the environment and the efficient utilization of raw materials are currently amongst the most important factors hindering the production of silicon. Poor leadership and managerial skills have also affected so many projects in the country. RLG communications, the Ghanaian tech company which was supposed to be spearheading the project known as “Hope City” failed due to poor leadership and managerial skills. Hope City was to have over 50,000 workers, all working in the field of information and communication technology who would be engaged in design and manufacturing of software and hardware for local consumption and export [19]. Figure 7 shows that Ghana has the financial capabilities to manufacture Integrated Circuit. However, the country has not yet commenced the manufacturing of Integrated Circuits. Currently, the country’s resource allocation to science and technology, which has fluctuated between 0.3 and 0.5 per cent of the Gross Domestic Product(GDP) is far below the target of one per cent of the GDP prescribed at summit of African Heads of State of the Organisation of African Unity in 1980 under the Lagos Plan of Action and adopted by the AU [20]. There is a need for Ghana to increase the country’s resource allocation to science and technology to influence the manufacturing of Integrated Circuits in Ghana. Figure 8 shows Ghana has the human resources for the manufacturing of Integrated Circuits since the country has a youthful population. However, this is not enough to manufacture Integrated Circuit. The semiconductor device manufacture is a long and delicate chain of events with more opportunity for failure than for success [21]. Therefore, people have to be trained and equipped to undertake this project. Unfortunately, Ghanaian organizations, both public and private,
do not give the necessary attention to human resource management issues. It is relevant to note that the development of human resources in Ghana since the mid-1960s have encountered two big problems. Firstly, the lack of competence staff in some critical sectors of Ghanaian economy. This is mainly because of lack of funding to provide the training needed at home or abroad. Second is the over-emphasis on liberal education which has ironically created a surplus in certain categories of skills [22]. This problem is exacerbated by a shortage of labor business knowledge, and lack of commercial and business cooperation education of skills development institutions and Ghanaian organizations that use those skills.

4.2.6. Establishment of an Integrated Circuit Manufacturing Company

Bringing up of an integrated circuit industry does happen just over night. A lot of time and planning is involved in its establishment. Given the necessary requirements, it takes more than two years to establish one semiconductor industry or fabrication centre [23]. According to the responses of students from the conducted survey, it would take about one to three years to establish a semiconductor industry.
CHAPTER FIVE

5. CHALLENGES

5.1. Introduction

Setting up a chip design and fabrication center comes its own challenges and these challenges are added to when it is to be sited in a developing country like Ghana. The basic challenge will be that, most of the workforce of the country have very low educational standards. The few who have attained high level of educational standards, mostly lack technical skills. The government polices of Ghana does not take technology into account as one of the major sectors of the nation’s economy to focus on improving it. Ghana is also a country that is yet to fully embrace research and development as one very important part of a nation’s economic growth, thus, there are very few research facilities in the country and these research facilities mainly focus their research on the agricultural sector. One main challenge faced is the initial expenditure involved in setting up a chip design and fabrication center which very high. Instruments and machines needed to set up these labs are priced in the millions of dollars. A whole chip fabrication lab costs billions of dollars to set up and various software licenses also cost huge chunk of money. Another disturbing challenge is the market and application of the various SoCs; what will be the consumer’s preference, how do we get people to know about the company’s products and the product range.

5.2. Human Resources

Industry’s engine is the people. This is truer nowhere than in the semiconductor industry. This business is not dependent on natural resource harvesting. In these industries, the key to success is literally human resources. The fast rate of innovation characterizing the semiconductor industry is driven by the proliferation of new ideas and new players. But this business and the innovation market as a whole are facing skills shortage that allows the recruitment of new workers into the
industry. The issue of human resources is divided into three main topics: academic institutions and courses, training and qualification [24].

5.2.1. Academic Institutions and Courses

In Ghana, there is a limited number of technical institutions or universities that focus on science and technology according to the Ministry of Education. This is seriously bad, taking into account the population and the number of Junior High School (JHS) and Senior High School (SHS) graduates. Some of these technical institutes also lack the academic programs to teach students about the emerging semiconductor technologies. The few of these institutes that have these academic programs or courses also teach students the practical sections of semiconductor technologies instead of adding the practical section of the courses too. This is due to the lack of facilities such as semiconductor labs which are required to train students [25].

5.2.2. Training

Before a person is placed in an industry, he or she goes through a series of training both in the industry as well as in an academic institution in the form of internship to enable him or her to acquire the proper skills to work in the industry. However, in Ghana, there is a lack of training programs to support emerging technologies. For some emerging technologies that are critical to the future of the semiconductor industry, such as artificial intelligence and autonomous driving systems, Ghanaian educational institutions are yet to develop their curriculum. The lack of such programs to support the development of highly qualified workers contributes to lack of skilled workforce. [26]. Also, there is a lack of resources to support the training of skilled personnel. Resources such as design software, fabrication labs and design tools for training purposes are not available in Ghana. Engineering graduates are then not able to acquire the proper skills and knowledge on chip manufacturing [27].
5.2.3. Qualification

As at 2019, the percentage of employees active in the agricultural, industry and service sectors were 35.5%, 18.62% and 47.88% respectively. In this case, engineers belong to the industry sector. From the percentages above, it is obvious most of the financial help is invested to the agricultural and service sectors whilst less is invested in the industry sector. It becomes very difficult to find qualified engineers to work in technological hubs and semiconductor industries, even when they become prominent in Ghana. Also, the few qualified personnel who go abroad to train for these semiconductor technologies end up staying there due to the lack of facilities in Ghana, hence, we lose the few workforce we have left [28]. In the next page is chart showing the distribution of employment by the economic sector from 2009 to 2019;

![Distribution of employment by the economic sector](image)

**Figure 5.1 Distribution of employment by the economic sector**

5.3. Research and Development

Research is the backbone of innovation. Without research, emerging technologies will not exist in the world. Effective transfer of technology depends on the availability of well-trained and qualified
engineers, researchers, and technicians. Currently South Korea is reputed to have one of the world's best education and R&D systems. Over the years, there has been no significant increase in student enrolment in science and engineering courses compared with other programmes. A study conducted at the Kwame Nkrumah University of Science and Technology (KNUST) showed that enrolment as a percentage of total university enrolment in the Bachelor of Arts and Management programs was more than 60 percent and still increased; engineering and science declined by 0.5 percent [29]. Three main challenges affect research and development in Ghana: inadequate research institutions, lack of resources to support research of semiconductor technologies and inadequate funding.

5.3.1. Lack of Technological Research Institutions

Many research institutions are located in Ghana. Some include; Kumasi Centre for Collaborative Research (KCCR), Oil Palm Research Institute (OPRI), Science and Technology Policy Research Institute (STEPRI) and Savana Agricultural Research Institute (SARI). However, only few technological institutions out of the many exist in the country. Most of the attention is given to research institutions in the agricultural and service sectors. The few research institutions that exist in Ghana lack technically skilled and trained manpower to conduct research on emerging semiconductor technologies. Due to the lack of these skilled researchers in the institutions, the level of innovativeness as well as the rate of innovation in the country is low [30].

5.3.2. Inadequate Research Facilities

For successful research focuses, certain environmental conditions must be satisfied. There should be the presence of laboratories, equipment, libraries and effective system for information storage, retrieval and utilization. The need for these facilities and their management is very obvious and calls for little emphasis. However, there are very few of these facilities in the few
semiconductor research facilities we have in the country. For example, for a particular chip to me manufactured, research must be conducted on it as well as the functions it will perform and a prototype of it must be developed to test it but the facilities needed for these processes are either limited or unavailable in Ghana. Also, negative institutional conditions such as poor infrastructure (equipment, laboratories and so forth) impose limitations on research and development of semiconductor technologies in the country [31].

5.3.3. Inadequate Funding

Ghana's science and technology programme is hampered by a number of constraints, primarily insufficient financing for R&D and lack of development of infrastructure. Sources of these funds include budget contributions from the government, and grants from donors. Policy promises on research grants have been insufficient for science and technology programs. Therefore, one can argue that Ghana is not competitively funding innovation, technical development and research. The country does not have the equivalent of the NICs of Asia's national and innovation research funding to monitor and review the implementation of effective research and innovation funding activities. In fact, there are no specific goals for research planning and programmes. The country's National Research and Innovation Fund (NRIF) which is yet to be formed will possibly fill this void, but it is not known for sure if the funds will be appropriate for universities, polytechnics and the private sector. Most research institutions and universities including institutions of science and technology do not do enough to encourage technical development and collaboration in the country. Science and technology support is exceptionally small according to international standards [32].
5.4. **Marketing / Application**

The increase proliferation of smartphones, tablets and feature phones as well as technological advances in consumer electronics devices are driving the growth of the IC market. The growing adoption of IoT in various industries is also expected to drive the growth of the market, showing the benefits of ICs in connected devices and applications [33]. The semiconductor industry should look forward to growth in the light of today's rapid technological progress. Demand for chips linked to the rapidly increasing use of AI would make a significant contribution to the overall growth of the industry. The race to capture the market is only intensifying, with competition from new startups and entrants from other corners of the tech world [34]. However, in Ghana, these semiconductor industries are not available to supply or sell schools and research institutions with the chips they need for their research and project works. In the case where Ghana would be able to produce ICs, more challenges will arise and some of these challenges include: consumer preference, product awareness, product range and business premises challenges.

5.4.1. **Consumer Preference**

A lot of recent calls have been made to Ghanaians to patronize local goods and services to help local producers and service providers remain in business and contribute to national economic growth. These calls came as a result of Ghanaians' low interest in patronizing local goods and services, and the related challenge it poses to industrial development and ultimately economic development in the region. Ghanaians have developed a strong preference for foreign technological devices hence even when a semiconductor industry is established to produce chips, to be sold in Ghana, citizens will still prefer the foreign ones because they will think the imported chips are of higher quality than those made locally. Today's result is that Ghana has become a huge
market for dumped goods, mostly including technological devices, from Europe and China leading to closures of the factories, unemployment and poverty. The few technological hubs located in the country are then unable to market their designed chips hence close down. Ghanaians prefer imported technological goods due to so many reasons. One of the reasons is the widespread belief that locally manufactured products are inferior in quality to foreign / imported goods, there are also persistent concerns about the high prices of locally manufactured objects. These high prices will mainly be due to the high costs of manufacturing. Many consumers in Ghana complain that goods produced domestically are expensive compared to other products of the same or higher quality imported into the country. Another factor driving buyers to patronize foreign goods over local goods is inadequate marketing of most local products. This aspect has many facets, the main ones being concerned with the marketing position in the manufacturing companies, management attitude towards customer interest, poor product planning, pricing and promotion. As Ghanaians, we are unable to advertise our locally produced products effectively, so how much more advertising technological products which most Ghanaians have little or no information on. Economic development is affected by marketing, hence, if we continue to patronize imported ICs instead of trying to setup industries to produce our own, the economy will be affected negatively thereby crippling it [35].

5.4.2. Product Awareness

For successful marketing, customers must have a degree of knowledge of the products they want to purchase. Customers include technological institutions who use the chips for project works and research, technological hubs and finally local vendors. In this case, the products are ICs or chips and for customers to purchase them, they must have the knowledge that the product exists as well as information about the product’s (IC) function, benefits, price, quality, compatibility and
Here is the case where most Ghanaians do not know about the various components that make up most of their electronic gadgets. From the survey conducted, people know of the electronic gadgets they use but do not know of functionality aspects of these gadgets to help them select the appropriate semiconductor device required for a particular purpose.

5.4.3. Product Range

In marketing, different variations of products known as product range appeals to a large set of customers. Variations such as size and functionality are the main criteria when it comes to attracting customers in the semiconductor industry. There are three main types of integrated circuits namely; thick and thin ICs, monolithic ICs and hybrid ICs. The thin and thick and monolithic integrated circuits are commonly used by students for academic purpose. However, hybrid integrated circuits are used in larger industries during the manufacturing and assembling of electronic equipment. Taking technology and research institutions into account in Ghana, most students know and use only the common types of ICs(thick and thin and monolithic ICs) for their project works but, in the case, where Ghana starts to manufacture different types of ICs, only the commonest ICs known to these students will be bought leaving the other important manufactured ones [37]. This then strains the economic budget since money is used to invest in the manufacturing of the different ICs produced.

5.4.4. Business Premises

Business location is important to maximize on passing trade. Choosing the right location is a challenge for businesses of all kinds, not just those that directly serve customers. Things such as
the demographics and educational level of the surrounding population who will be potential employees, schools in the area who train workers for particular occupations, and the availability and quality of either affordable family housing or viable public transit all affect how effective a business will be in any given area. Ghana is still on its way advancing science and technology and also people often do not really have the ICT skills. Due to this lack of ICT skills, Science and Technology projects like the manufacturing of Integrated Circuit would be affected since no one would like to partake in the digital economy if there is no knowledge about the technology.

5.5. Policies
The importance of the structural approach for policy management of innovation as a key to national development in the sense of a knowledge-based economy is becoming increasingly apparent to policy makers. The creation, accumulation and dissemination of knowledge through organizational, human and social capital structures, networks and assets remain the outstanding feature of innovation. To maximize national competitive advantage by leveraging both types, it is important for government policymakers to use existing policy tools effectively and efficiently and to design new policies based on empirical evidence as a function of significant variables. These variables should be designed and optimized to surmount innovation barriers. The vision of Ghana in policy making in the technological sector is to provide access to education services so that Ghana’s human capital can better contribute to achieving modern economy more heavily based on successful application and implementation of science and technology production as well as transform Ghana into the technological age [38]. Currently, Ghana does not have policies that govern the introduction of semiconductor technology but have few policies that govern
Information and Communication Technologies (ICT). Below are some objectives of technology (ICT) policies;

1. To aid the process of the development of national human resource capacity and the nation’s R&D capabilities to meet the changing needs and demands of the economy [39].

2. To support the development of a viable knowledge-based ICT industry to facilitate the production, manufacturing, development, delivering, and distribution of ICT products and services [39].

3. To guide the development and implementation of electronic government and governance, as well as electronic commerce and business strategies and action plans [39].

4. To facilitate the development and promotion of the necessary standards, good practices and guidelines to support the deployment and exploitation of ICTs within the society and economy [39].

5. To create the necessary enabling environment to facilitate the deployment, utilization and exploitation of ICTs within the economy and society [39].

Policy Challenges

It is recognized that Ghana will need to establish and enforce comprehensive integrated technology-led socio-economic development policies, strategies and plans set within the broader context of the country's socio-economic development goals if it is to move its industrially poor, subsistence agriculture-based economy towards an information and knowledge economy. There is no question that Ghana will need to adopt and leverage ICTs to accelerate its growth process, in order to survive and flourish in the current emerging global economy to be dominated by information and knowledge-based economies [40]. The success of Ghana in the current technology revolution and technological era will depend on how well it manages to overcome the resulting
developmental challenges and take advantage of rapidly changing technologies. Though Ghana can make the idea of domination of technology work, some few policy challenges present themselves;

i. Creation and Implementation of Policies [40].

ii. Ghana has a predominantly agricultural economy hence the majority of the working population (60%) are still actively involved in agriculture with only 13% working in the industrial sector and 28% in the service sector of the economy [40].

iii. The job creation capacity of the Ghanaian economy is extremely low.

iv. Ghana is currently facing a human resource problem in technical and managerial skills and more so in the area of technological skills [40].

v. Ghana’s R&D capacity and capabilities are limited, with the nation’s universities and research institutions lacking the necessary capacity to conduct and engage in advanced and cutting-edge R&D work [40].

5.5.1. Creation and Implementation of Policies

For decisions to be made regarding a particular factor in the country, policies need to be created to guide the decision and achieve rational outcomes. Policy implementation is the process of changing a formulated policy into reality [41]. Policy implementation problems in Ghana may be attributed to inadequate preparation, political uncertainty and bureaucratic bottlenecks, deliberate policy intrusion, full alteration of the plan unless it is in favor of implementers or civil servants who are responsible for implementing it. Ghana has no or little issue with policy strategy or formulating than the policy implementation challenge. One of the problems of policy development is the failure of target beneficiaries to engage in the policy process. Policy implementation usually
fail because the rural areas are neglected and also policies are designed and planned without proper management, thus policies are imposed by the government without considering whether it meets the needs of citizens or not. Relating this to semiconductor or IC technology, there are just few policies that govern the technology, thus Information and Communications Technologies. Out of these few policies none of them relate to the introduction or creation of new technologies in the country. Ghana cannot adequately implement semiconductor technology goals due to the lack of human and materials capacity [42].

5.5.2. Domination of Economy by Agriculture

The Ghanaian economy is still largely agricultural-based without a major change towards the services and manufacturing sector as planned if the economy is on a rapid path of growth and modernization. The structure of the Ghanaian economy calculated in terms of sectoral contribution to GDP suggests that in the last 20 years, the structure of the economy has changed very little. Implementing policies and strategies to modernize the agricultural sector while at the same time targeting the growth of the manufacturing and service sectors in order to increase their contribution to GDP is a major developmental change facing the country [43]. Focusing on the industry, not much attention is given to manufacturing companies to develop them, therefore, in the case where Ghana is to set up a semiconductor or IC industry it is very likely that no or little attention and support will be given to the industry in order to improve industrialization and development in the country.
5.5.3. Job Creation Capacity

About 68 percent of the working population are self-employed and have no jobs. In other words, the bulk of the labor force operates in their own small businesses and have no other workers aside from themselves. With the economy dominated by the self-employed, who do not have the resources to hire anyone, there is very little prospect of creating new jobs or employment prospects.
for a rising young population [43]. A main structural challenge facing the country is the transformation of the economy to boost its job generation potential.

5.5.4. Human Resource Problem

The economically active population's occupational profile shows that: just 8.6 percent are specialists and skilled people who are managers and administrators with a lower proportion of 0.3 per cent. Ghana is estimated to have about 174 registered engineers, 53 law practitioners, 60 certified accountants, 50 architects and surveyors and 145 medical and information practitioners (including doctors) per million people. The low percentage of key technical and specialist labor highlights the economy's relatively limited potential for specialized and technically qualified human capital [43]. This shows there are less skilled, professional and technical manpower to work in a semiconductor industry, should one be established in Ghana. Developing a qualified human resource workforce can be highlighted as one of the country's main growth challenges.

5.6. Financing

The semiconductor industry has slowly developed into a mature sector, after witnessing fast growth for many decades. Overall business growth has moderated substantially; the global economy is projected to have risen to just 0.3 percent as it now stands at $341 billion, compared with a compound annual growth rate of 7.6 percent from 1990 to 2015. The amount of capital and the time required to finance a start-up semiconductor business through profitability has greatly increased. Such factors make it more difficult to have access to capital to finance innovative innovations and in the coming decades the industry will need new funding mechanisms to promote innovation. Given these headwinds, there are strength pockets in areas such as fuel, sensors and the automotive. For example, growth in the power semiconductor market continues to outpace the overall market driven by demand for higher output and fewer form factors [45]. However, Ghana
doesn’t have these industries to produce ICs mainly due to financial reasons. Four main financing challenges are highlighted in this section; Research and Development financing challenges, Human Resource financing challenges, Software Licensing financing challenges and last but not least Structural financing challenges.

5.6.1. Research and Development Financing

It is commonly held that research and development (R&D) operations in a openly competitive market place are difficult to fund. R&D has a number of features which distinguish it from ordinary investment. First and most notably, the wages and salaries of highly qualified scientists and engineers are in fact fifty per cent or more of R&D spending. A second important aspect of investment in research and development is the degree of uncertainty associated with its production. At the beginning of a research program or project, this ambiguity appears to be highest, suggesting that an optimal R&D approach has an option-like character and should not be evaluated in a static sense. R&D projects with low odds of great future success can be worth pursuing, even if they do not pass the anticipated return test. All these procedures need financial support in order to be successful. In Ghana, less than one percent (1%) of the Gross Domestic Product (GDP) is spent on research and development, a study by the world bank. The study claimed that since 2007, Ghana has continuously pumped 0.38 percent of its GDP through research. Meanwhile, countries such as Japan, Sweden, South Korea and Finland are investing over 4% of their GDPs on research and due to this they are successful in their R&D capabilities [46].

Below and in the next page are some graphs indicating the investments of GDPs by other countries:
Figure 5.4  First Graph indicating the investments of GDPs by some countries

The world invests 2.1 percent of global GDP in research and development.
5.6.2. Establishment of Design and Fabrication Centres

The putting up of a SoC design and fabrication centre is a venture that requires investment in the estimate in the billions of US dollars. Fabrication labs require many expensive equipment in order to function. Estimates put the cost of building a new fabrication lab to over 1 billion US dollars with values as high as 3-4 billion US dollars which is not uncommon. The central part of a fabrication lab is the clean room. The clean room must be 1000 times cleaner than a medical operating room because even a small particle can ruin a whole IC, thus, the clean room building should be fortified against impurities. The clean room also contains equipment such as stepper for
photolithography, etching, cleaning, doping and dicing machines. All these devices are extremely precise and thus very expensive.

Below are some fabrication centres or plants in the world as well as their worth [47]:

<table>
<thead>
<tr>
<th>Company</th>
<th>Plant Name</th>
<th>Plant Location</th>
<th>Plant Cost (in US$ billions)</th>
<th>Started Production</th>
<th>Wafer Size (mm)</th>
<th>Process Technology Node (nm)</th>
<th>Hide Technology / Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silterra</td>
<td>Fab1</td>
<td>Malaysia, Kedah, Kulim</td>
<td>1.6</td>
<td>2000</td>
<td>200</td>
<td>90-180</td>
<td>CMOS, HV, MEMS, RF, Logic, Analog, Mix Signal</td>
</tr>
<tr>
<td>CanSemi</td>
<td></td>
<td>China, Guanzhou</td>
<td>4</td>
<td>300</td>
<td></td>
<td>180-130</td>
<td>Foundry</td>
</tr>
<tr>
<td>Nanya</td>
<td>Fab 2</td>
<td>Taiwan, Linkou</td>
<td>0.8</td>
<td>2000</td>
<td>200</td>
<td>175</td>
<td>DRAM</td>
</tr>
<tr>
<td>Company</td>
<td>Fab</td>
<td>Location</td>
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<td>Year</td>
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<td>2020, February 20</td>
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<td>65-11</td>
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Taking a look at these numbers and considering the amount of capital Ghana puts just into the agricultural sector, it will be a tough challenge to set up and maintain even only one design and fabrication plant in the country.

5.6.3. IC Design Software Tool and License Financing

Software is an intellectual property. Most often, it is licensed by means of a licensing agreement with third-party vendors [48]. With the license agreement comes

- *rights* – such as the right to use the software under certain licensing restrictions, and
- *duties* – such as license and maintenance costs.

At each new process node, the costs of SoC silicon and software design are rising, with increasing emphasis now being placed on the software side of design cost equation. Figure 1 shows an estimate of design costs which were estimated to be around US$15M, contained largely though continuing advances in IC implementation tools [49].
Figure 5.6 Rising cost of and effect of CAD tools in containing these cost

Also, semiconductor design tools are relatively costly. An Application Specific Integrated Circuit (ASIC) design tool too seat software may cost over $100,000 while Field-Programmable Gate Array (FPGA) design tool seat runs over $10,000 [50]. Analyzing the figures, it comes to the realization that Ghana indeed will face a lot of challenges obtaining software design tools for manufacturing Integrated Circuit in Ghana since science and technology projects in Ghana are ill-funded [51].

In revenue model, for any new deal signed, the intellectual property (IP) vendor will charge an up-front premium called a license fee. Based on factors such as the complexity of the IP, cost of development, target applications and expected volumes, a license fee can vary from a hundred thousand US dollars ($100,000) to one million US dollars ($1,000,000) [52].
CHAPTER SIX

6. RECOMMENDATIONS AND OPPORTUNITIES

6.1. Introduction

In this age of the technological world advancement, the idea of setting up and investing in design and fabrication centers is a good initiative. This gets even better when such initiatives are undertaken place in a country like Ghana. There is of course a downside to every initiative, but the positivity and opportunities here far outweighs the number of setbacks that could occur. There so many advantages to setting up a design and fabrication center in the country. One major advantage of setting a fabrication center in Ghana is the vast availability of natural resources in the country. Also, there is a large educated, skilled and unemployed labor force ready to deliver their best to what they do and serve society. There are also few but enhanced facilities in Ghana such as tech hubs and incubators that would be essential to the activities and progress of a chip design and fabrication center. The set up will also help rekindle the interest of people in the integrated circuit and SoC technological field. Ghana and its neighboring countries lacking such a set up simply means there is whole new market to be exploited and a whole technological system to advanced.

6.2. Opportunities for Producing Integrated Circuits in Ghana

6.2.1. Natural Resource Availability and Utilization

One major element essential to production of chips is silicon and one rich source of silicon is sand which is in much abundance in this country. Ghana being a tropical country with a coastal border and mountainous scalps, sand and sandy rocks are in abundance. Setting up a silicon wafer processing plant and hence a chip fabrication center will be much cheaper and easier in terms of acquiring raw materials for processing and manufacturing of the SoCs. Sand is a resource in Ghana that is much under-utilized. The only use of sand in Ghana is only for constructional purposes such
housing, road and bridge constructions and these purposes under-utilize the sand resource which is in much abundance compared to other resources such as gold and crude oil which are over exploited. Setting up silicon wafer processing plant and fabrication centers in Ghana will lead to efficient utilization of sand resources and relief some pressure of some resources since they are over exploited in order to serve as primary revenue to the country’s economy.

6.2.2. Benefiting and Utilization Various Technological Hubs in the Country

There are about 25 technological hubs and a number of tech incubators all around the country [53]. These hubs and incubators have various technological resources in the field of Integrated Circuits, SoC design and fabrication of chips that could be essential to a new fabrication setup. These hubs mostly have design centers which implies they most probably have possession of already made chip designs that would be essential to new chip fabrication center. Their floor plans, designs and layout could be as building blocks to improve the rapid growth of the enterprise. Their available facilities such as design centers, could also be used for various design works to avoid large expenditures in building one and that capital could be focused on developing other sectors of the enterprise. These hubs can also provide technological assistance and advice to the enterprise since they are mostly abreast of various technological advancements [54].
6.2.3. **Human Resource Availability**

A great number of electronic and computer engineers and scientists graduate from tertiary institutions all over the country every year. Most of these graduates possess some knowledge in chip design and manufacturing because it is mainly incorporated into their academic curriculum. For the sake of this, recruiting personnel for certain tasks becomes easier and simpler. Training recruits becomes much easier and faster due to their already educational status of having a background in chip designs and fabrication. There are also trained and experienced people who have had first hand experiences with chip design and fabrication in different part in the country. There are also skilled personnel in the various technological hubs in the country who can fit into various positions in the set up and perform various tasks assigned to them assiduously and effectively. The unemployment rate of Ghana is at 4.16 (2018 unemployment data) [55], meaning there are a lot of skilled and educated individuals with no apparent jobs in the country at the
moment. Getting the qualified individuals to work in the design and fabrication center will be easy and will also go a long way to reduce the unemployment in the country.

6.3. **Recommendations**

6.3.1. **Technological Advancement**

Ghana’s as a country is used to the primitive way of doing things. Most of the Ghanaian technological inputs are mostly hand driven and mechanical with very few making use of low automation technology. One particular reason for this setback is not the fact that Ghanaians do not desire to advance in the field of technology but this is due the fact individuals and the country as a whole lack the various facilities, an example being a design and fabrication center, which will transform their various ideas about various technological issues into real life solutions. The few who still do venture into making their face a lot of challenges in doing so in the sense that even they are able to complete their designs with the resources available, they have to send their designs to countries abroad with fabrication centers to get it fabricated which causes them to lose a great deal of resources in doing so. Setting up a design and fabrication center in the country will help motivate various individual with various technological initiatives and problem solving to ideas to put their ideas to work since there are work centers for them to implement them. With the increase in the technological initiatives and ideas being implemented, the country’s technological advancement thus grows accordingly.

6.3.2. **A Virgin Market to be Exploited**

Ghana is a country looking to join the upstream of technological advancement in the world. Many engineers, scientists and chip designers are looking to put their various ideas unto chips. These goals have become so hard to materialize them because engineers and chip designers find it really difficult to fabricate their designs into actual chips. There are no known modernized chip
fabrication labs in the whole of Africa which means engineers and chip designers have to send their designs and layout abroad to be fabricated. Not even taking into account the cost involved in sending one’s design upstate to be fabricated which is enormously high, the waiting time involved is very long considering various procedures and processes to follow and also the matter of the geographical distance is quite long. Setting up a Fabrication center in the country will not only make one the sole owner of the fabrication market in the country but also the African continent as a whole. Setting up a Fabrication center in the country will motivate many engineers and chip designers whom capital and time has been their sole hinderance in venturing into technological designs and problem solving to get back at it. This then also creates a larger market for chip manufacturing.
CHAPTER SEVEN

7. CONCLUSION

Integrated chips (ICs) have become an important commodity of our ever-growing technological society in the view of making the world a global village. Integrated circuits have come a long way in shaping our data processing and information handling technology. Making them faster and more reliable, with additional features, they occupying relatively much smaller spaces and consuming less power. Ghana as a country venturing into the production of integrated circuits will not be monetarily profitable but will also go a long way to enhance its technological advancement. But the process to setting up IC production company in Ghana is faced by many challenges. One being the fact that almost all research institutions in the country being mainly centered on agriculture and service sector leaving a very few for the technological center. The human labor existing in the country has its majority with low to no educational background. There being a very limited number of technical institution and universities in the country, training of the country’s workforce thus becomes a challenge. Also, these institutions mostly lack various curriculums that will help train and educate students about emerging IC technologies. The polices and budgets of the country, as seen over the years, has not given much attention to the technological sector as it does for other sectors. This might be to their ill-education on how important integrated circuit and hence the technological sector is important to the country’s economic growth. Another challenge faced is the identification of the target market for the various ICs to be produced and the various individuals and institutions who will be involved with the company. One major challenge is the capital needed to set up an IC fabrication company. The cost of putting up a fabrication lab is in the billions of dollars which makes acquiring capital to put up one so difficult. With all these challenges out the way, the IC fabrication company is an assured profitable company. There are various upsides to
setting up an IC fabrication company in Ghana. Ghana is a country rich in natural resources and this will help enable easy access to raw materials. There are also various technological hubs and incubators in the country willing to provide advice and expertise when called upon. They also possess some state-of-the-art facilities IC design centers that can really be beneficial to an IC fabrication company. Setting up an IC fabrication center in Ghana will not only be economically beneficial to growth of the and/or any individual involved, but this will also help the nation take a great step toward the pursuit for the nation’s technological advancement.
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