Preface

The main reason I am writing this book is to get history right and set the records straight on the invention of the integrated circuits (ICs). Getting history right can be a monumental, daunting and an unrewarding task. This is especially true if the subject matter is of fundamental importance and wide popularity having direct impact on the bottom line of a huge market. The task is compounded further if its prevailing view has been misleading, and has lasted for a long time, e.g., for more than four decades in this case of the invention of ICs. Another dimension is added to its monumental aspect when world caliber and colorful personalities in highly respected institutions with impeccable records are involved in this whole saga of the mystery of the IC invention. Almost everybody in the microelectronics field involving physics, chemistry, engineering etc in the entire world appear to have accepted the erroneous information of the IC invention for more than four decades because they have done nothing so far to correct it. Nevertheless despite the daunting aspect of the task, I feel that it needs to be done because it is important to get history right. The previous accounts of the invention of ICs given by several science history writers have been erroneous. I shall give all the relevant and well documented facts to set the records straight, and get history right for the invention of ICs in this book. These facts can be verified by anybody, as it is the accepted hallmark procedure in good scientific research: any result claimed must be verifiable by independent workers. However, this book has not been written like an esoteric thesis. It reads like a mystery novel, but the intrigues and their solutions are given in an easy to read style based on well established facts. The readers will find it amazing that the real truth of the IC invention has been swept under the rug earlier by the powers to be in a manner unparalleled in the history of mankind. A capsule of the details given in various chapters is presented in this Preface. I hope that the brief discussion given below will make a compelling case for reading and enjoying this book, and to learn about the facts of this historic invention which has changed mankind forever.

For the sake of convenience of the readers, I shall repeat the discussions of some of the important facts and published documents in appropriate places to avoid going back and forth in this book. Since the misleading information on the invention of ICs has lasted in the literature for such a long time, it is particularly important to give credible documentation and discussions even repeatedly. This is meant to convince the readers and rectify the misinformation that has been prevailing all these 40+ years all over the world. Also those who may not be familiar with the various scientific abbreviations, acronyms and symbols, I shall repeat them a few times so that the readers will become conversant with their usage in this book. However, all the abbreviations, acronyms and symbols are also defined and listed in Appendix 6.

1. Getting History Right

Why getting history right is important? Being cognizant of the yore so that the past mistakes shall not be repeated is a prudent wisdom to follow, as we forge ahead with innovations and improvements in the future. The expanded version of the adage "Those who do not learn from their elders' wisdom and experiences, and their own past mistakes, are condemned to relive them", has been proven repeatedly throughout the history of human endeavor including scientific research. The inspiration for the younger generation to innovate for the future is provided by the leaders of the past. If the past accomplishments are misrepresented by the spin meisters of the present, it negates this key process of progeny of innovation for the future. Those who stop innovating and stop keeping up with the critical inventions indispensable in our daily lives are left behind and destined to lose, collapse, and demise not unlike the Roman Empire. Therefore getting history right is of utmost importance and that is the purpose of this book.

2. Importance of the IC Invention

Since the creation of human life and evolution of human intelligence, there has been no invention more important than the IC for the development and progress of mankind at least from the mid 20^{th} century onwards.

Earlier, the industrial revolution, the printing press, and the agricultural revolution also revolutionized the human life. However, even these earlier outstanding innovations have needed the enhancements enabled by the present ICs used in their control systems, without which their efficiencies and efficacies cannot be harnessed as well as it has been attained today. Almost no business can operate, and to make a bold but true statement, almost no human at least in the developed countries can carry on with their lives without an IC. Its use is indispensable worldwide in many applications (partial list given alphabetically): banking, biotechnology, communications, computers, education, entertainment, government, hospitals, internet, medicine,nanotechnology, research, travel, and in almost every commercial, defense and industrial businesses. All the electronic systems in these applications currently use Ultra Large Scale ICs (ULSICs) which are much more advanced and complex than the ICs invented originally. However, the stems of all ULSICs are rooted in the basic invention of the ICs 50 years ago. The ULSIC business has now grown to multi-hundred billion dollars annually, which is the heart and soul of the entire electronic systems market place of several trillion dollars per year. The growth of this ULSIC business and its impact on the society and newer businesses shall forever be increasing. Therefore it is important to know what were the basic inventions of the ICs, who invented them, when and how.

3. What is an IC?

The details of "What is an IC?" have been given in Chapter 1 and in subsequent chapters in this book. Briefly, an IC is an electronic circuit consisting of various active (transistors) and passive (resistors and capacitors) devices integrated electrically by interconnecting them with single or multilevel metallizations delineated as thin, narrow, electrically conducting metal lines on a piece of single crystal silicon (Si). It is popularly referred to as the chip. The only kind of ICs sold from the very beginning have been the monolithic-ICs, commonly termed as just the ICs, made from Si. An exception to this statement are the microwave ICs which are hybrid consisting of Si monolithic-ICs and those fabricated from compound semiconductors. One of the technologies mandatory for the fabrication of Si monolithic-ICs is called the planar technology. The reason I am mentioning about it here in the Preface is that Jean Hoerni of Fairchild is given the sole credit for the invention of the planar technology. Even though this book is to correct the history of the invention of IC, it is also important to know the truth about "Who invented the planar technology?" since the ICs cannot be fabricated without it. The readers will be surprised to learn from the documented facts given in Chapter 6 that the invention of the planar technology was built upon the original work of several other people done earlier. Hoerni had combined all this information to reduce to practice the very first transistors fabricated with planar technology. Immediately after this accomplishment, Hoerni had filed and received his patents to claim the planar technology invention. The other earlier inventors and contributors of each of the basic building-blocks of the planar technology did not do anything about it and they were ignored. This is another mystery added to the saga of the invention of ICs which has been officially and popularly recognized as the invention only by Kilby and Noyce, which is the main focus of this book.

4. Sole Credit to Kilby and Noyce

The sole credit for the invention of ICs has been given in the literature to late Jack Kilby and late Bob Noyce after their inventions were disclosed in their respective patent filings at the US Patent and Trademark Office (USPTO) about 50 years ago. Unfortunately this recognition accorded to Kilby and Noyce is only partially correct and justifiable. Most of the other authors on this subject have failed to appreciate the fallacy of this exclusive recognition. Indeed Kilby and Noyce did play key roles in the invention of ICs, but not quite the way they have been portrayed in the literature. For example, they have been credited in folkloric manner as if they had invented the IC all by themselves, thereby given an iconic stature by the hero worshippers. Moreover, some of the important facts have either been overlooked or not understood at all by the previous authors and those publicizing such folklore. These facts have been documented in this book. They tell an accurate but different story about the real contributions of Kilby and Noyce.

The readers will find here in my book, that Kilby's descriptions and documentations underlying the concepts of the ICs were incomplete. He had missed the key requirements which are: the devices must be connected also by monolithic interconnects adherent to the surface layers (not by gold wires bonded to the devices and flopping in the air above the chip which Kilby had used), and the planar (not mesa) technology must be used to fabricate and electrically isolate the devices in a piece of single crystal semiconductor such as Si.

The IC concepts described by Kilby in his patents had a striking similarity to those published earlier by Dummer. Moreover, such similarity was also limited and confined only to the same incomplete and partial description of the IC concepts described independently by Dummer earlier. These points raise intriguing questions and speculations of possibly borrowing from the past and forgetting to acknowledge the previous contributor(s). Another way to express such actions is that as if surreptitious or deliberate plagiarism was done, although one cannot prove it. Similar practice appears to be popular among some of the authors on the history of ICs when they continue to condone the incorrect facts of such an important invention. Some aspects of these practices may be debatable; they can also be excused due to the vast literature and the limited human (rather than computer) search engines available in the earlier times. Kilby, however, did refer to Dummer's concepts in his post-patent journal articles and in his Nobel speech much later (in 2000), but not in his patents filed 41 years earlier in 1959. This is called "acknowledgement after the fact", or "post facto acknowledgement", or "reconnaissance après coup", or "nachträgliche Anerkennung", or "scoperte a posteriori", or "pahley churaya, baad mein shukriya", or whatever in several other languages.

In addition to the equivalence of the Kilby's description of the IC concepts to that of Dummer earlier, essentially similar basic ideas were also described by Johnson of RCA and Stewart of Texas Instruments (TI), earlier than Kilby. Stewart had been working at TI for a few years before Kilby had joined TI in 1958. Kilby did not acknowledge either Johnson's or Stewart's concepts in his patents or papers. Of these two contributors, it is more surprising that Stewart was ignored because both he and Kilby had been working in the same company, viz., TI, at that time and Stewart's patent was issued even exactly on the same date as Kilby's IC patents.

5. Key Points to Get History Right

The key points given briefly in the subsequent sections of this Preface are very important to get history right about the invention of ICs. They will become clearer after reading their details in the book. Some of them will startle and surprise many people, including the scholars. But my key objective is not to sensationalize such an important invention. I shall present the facts many of which have not been reported earlier in the literature correctly. These facts have been derived by me from Kilby's and Noyce's published documents such as their US patents and journal articles, and my communications with other authoritative sources such as the United States Patent and Trademark Office (USPTO), Nobel Committee members, and several other original contributors to the invention of ICs. Some of the facts are also based on my first hand knowledge of participating and contributing in the historic events from the inception of the invention by Bob Noyce to the subsequent advancement of the ICs when working in R & D at Fairchild directed by Gordon Moore, and elsewhere. The technical nature of the facts given below can be understood better by the scientists and engineers in the microelectronics field, than by the laypersons. Nevertheless even the laypersons can appreciate the significance of most of these facts after reading this book. All the readers will find that the saga of the invention of ICs is quite different from what has generally been described in the literature. It is amazing that the entire popular story of the invention of ICs has the makings of a mystery novel. But this book is based on facts, not on fiction; hopefully the readers will find it engrossing, educational and entertaining as well.

In order to set the stage for this book, the key points of Kilby's and Noyce's inventions of the ICs are summarized at the outset. If some of them come to you (the reader, even the experienced ones in the IC profession) as a surprise, please do not get alarmed; be inquisitive with an open mind and learn from the facts given in this book.

6. Key Points of Jack S. Kilby's Invention

6.1. Kilby did not invent the monolithic-ICs made from silicon (Si), the only kind sold from the very beginning in the microelectronics business in 1960 and onwards. (An exception to this statement is the microwave IC.) This fact was also confirmed by a Nobel Committee member in his recent written communications with me regarding Kilby's invention and the Nobel Prize in Physics awarded to him in 2000. It will surprise particularly many of the diehards who are of the firm opinion that the Nobel Committee decisions to give the awards in Physics are always non-controversial. They assume that such decisions to select the Nobel Prize awardees must be based on precise incontrovertible principles of physics.

6.2. Kilby's suggestion to fabricate multiple devices within a single piece of semiconductor was of course a key but only a small contribution. Similar suggestions had been made earlier than Kilby by other authors, e.g, Geoffrey Dummer in England, Harwick Johnson of RCA and Richard Stewart also of Texas Instruments (as Kilby was from TI too but joined TI later) right here in the USA.

6.3. Kilby's original disclosure, issued patent(s), and reduction to practice did not specify nor use the planar technology to fabricate the devices which is mandatory for monolithic-ICs made with silicon (Si). For reduction to practice, Kilby had used mesa technology and germanium (Ge).

6.4. Kilby had used gold (Au) wires bonded to the devices made in germanium (Ge) pieces to interconnect them, flopping over the chip from one device to another to complete his IC. The monolithic interconnects to connect electrically the various devices on a chip, which should also be adherent to the insulator layers, were neither specified correctly nor used by Kilby. It was adjudged by the Board of Appeals of USPTO to be a key omission by Kilby. This fact alone, over and beyond a few other serious drawbacks in his patent(s), had cost Kilby the sole ownership of the IC invention.

6.5. Kilby's specification for the electrical isolation of devices in a chip was mesa technology, which has never been used in Si monolithic-ICs. The monolithic p-n junction isolation process was invented by Kurt Lehovec of Sprague Electric Company earlier. Kilby lost the patent interference to Lehovec, as his claim to have anticipated Lehovec's invention was rejected by the USPTO.

6.6. Kilby continued to regard the monolithic concept as controversial until as recently as in his 1998 IEEE Proceedings article discussing the invention of IC. There has been no controversy about the monolithic concept since the silicon (Si) monolithic-ICs were sold from the very beginning in 1960 and onwards. If anybody who should have been crystal clear about the monolithic concept, it should have been Kilby, because the company he had worked for, Texas Instruments (TI) was among the first to sell the silicon (Si) monolithic-ICs in the entire market at the time and soon after filing of the Kilby patents.

6.7. Kilby's patent(s) were awarded a few years after Noyce was awarded his patent, even though Kilby had filed earlier than Noyce. The filing date of Kilby's Original Application (OA) in 1959 appears never to have been resolved, as evidenced by the recent communications of USPTO with me in 2005 (46 years after the original filing). In addition, it appears that the laws of the US Patent code 35 USC 112 and associated protocols were possibly compromised in the procedures used by USPTO to issue the patents to Kilby, as documented by their filing dates, specifications and claims.

6.8. The quintessence of Nobel's Will is that the Nobel Prizes shall be awarded to person(s) irrespective of nationality who, during the preceding year has (have) conferred the greatest benefit on mankind. For detailed discussions of the Nobel Prizes in Physics awarded throughout their entire history, and for the Nobel Prize given to Alferov, Kroemer and Kilby, see Appendix 7. See chapters 1 and 12 also for the technical issues related to the IC invention. Nobel Prize is not awarded in the field of Engineering. The Nobel Prize in physics [7] was awarded in 2000 jointly to Alferov, Kroemer and Kilby, and their names were listed in this order. Noyce had died in 1990; the Nobel Prizes are not awarded posthumously. Had Noyce not died, in my opinion he would have been definitely included in this award. Perhaps then the entire Nobel Prize award would have been worded and even awarded differently. The inventions of Kilby and Noyce did not involve any basic contributions to physics. However, the work of Alferov and Kroemer did involve basic contributions to physics.

The Nobel Prize money was distributed as ¼ each to Alferov and Kroemer, but ½ to Kilby. The citation of the Nobel Award to Kilby did not explain what was his part to invent what kind of IC? Kilby's citation in the Prize was incomplete and inconsistent with his contribution to the purported invention of monolithic-ICs for which he was given the Nobel award. No explanation has been offered so far by the Nobel Committee for the vague and imprecise citation of such an important world renowned Prize.

I had written communications in 2006 with two members of the Nobel Committee which was responsible for the Nobel award in Physics in 2000. To the best of my knowledge, I was the first to raise the issues of the incomplete characterization in the citation of the award to Kilby. They had invoked Nobel's original Will, and declined to answer my questions. An aura of mystery was created in these communications because neither clarifications of Kilby's invention nor any further recourse to get them were given. This mystery was heightened also by the refusal of Nobel Committee to explain why Kilby was given twice the amount of financial award than to each of the other two co-recipients whose fundamental contributions did involve physics? Such a monetary award was unlike the equal amounts given in the Nobel Prize in Physics awarded to Shockley, Bardeen and Brattain for their invention of the transistor earlier in 1956. Additional fact that remained unexplained was that neither the listing of Shockley, Bardeen and Brattain in 1956, nor that of Alferov, Kroemer and Kilby in 2000 had followed an alphabetical order. Most of the other 3-person recipients of the Nobel Prizes in Physics had been listed alphabetically throughout the history of the Nobel awards (see Appendix 7). The readers would come away with the impression that Shockley was the senior recipient because he was listed first, not in alphabetical order, in 1956. However, as mentioned above, from the monetary aspects of the Nobel award he was not the senior recipient because he had received equal amounts as given to Bardeen and Brattain. As discussed above, Kilby was listed as the last person in the Nobel award in 2000, not listed alphabetically. Most of the readers would know from the popular literature that Kilby's award was for the invention of the IC. They might get the impression that Kilby being listed as the last person in the 3-person Nobel award may signify that the Nobel Committee regarded the invention of IC as less important than that the inventions in optoelectronics by Alferov and Kroemer. But the readers would not normally realize that from the monetary aspect of the award. Kilby was actually the senior most recipient because he got twice the amount of prize money than the other two recipients. These are the facts which can give confusing and misleading information to the readers about the Nobel award in 2000 and about the original intention of the Nobel

Committee. These facts, however, do not clarify the actions of the Nobel Committee. (See Appendix 7 for details.)

It is generally known that the highly revered private group of the Nobel Committee acts as a powerful closed institution which feels strongly that they do not owe any explanation to anyone regarding their choices and decisions. Without casting any aspersions on any party concerned, respectfully and punctiliously I only wish to state that the manner in which Kilby's Nobel citation and award had been handled was quite inexplicable. My communications with the Nobel Committee and their refusal to shed light on both the citation of the award and the double amount of the financial award to Kilby, had created more intrigue to the mystery. Nevertheless one cannot obliterate the facts as published by the Nobel Committee itself and elsewhere in the literature. They are cast in concrete and therefore stated as such in this book. However I have done further research using the original Nobel website on the Nobel Awards in Physics throughout their entire history of existence. Based on my research, I can offer an explanation only for the sequence of listing of the names, and the unequal financial awards by the Nobel Committee to Alferov, Kroemer and Kilby. Such an explanation deduced by me from the facts of the Nobel Awards for the first time in the literature, has not been given by Nobel Committee or anyone else ever before. But I still cannot fathom the imprecise citation of the award and the choice of Kilby by the Nobel Committee, which remains a mystery. For details, see Appendix 7 and chapter 12.

The above list may give an erroneous impression to a casual reader as if Kilby, USPTO and the Nobel Committee are being assailed. However an unbiased, knowledgeable and serious reader will find that such is not the case at all in this book. As I have stated in my paper(s) published recently, Kilby did make a key contribution to the invention of ICs, but it was only a small part of the complete invention needed. This will become even clearer after reading this book. Kilby was a great man who went on to make important contributions to other technologies thereafter, but not to the ICs after his part of the invention was allowed as patents by the USPTO. The procedures of USPTO itself used in the processing of Kilby's applications and patents in the 1960s were circumspect if the laws of US Patent code 35 USC 112 and associated protocols are taken into account.

The Nobel Committee consists of highly qualified people belonging to a highly respected institution with an impeccable record. But as one of my late very distinguished physicist professor, who had produced both PhDs and Nobel Laureates, had told me recently in a tongue-in-cheek manner, "You must not forget that they are also human beings who can be fallible sometimes!"

7. Key Points of Robert (Bob) N. Noyce's Invention

Most of the key points of Noyce's invention of ICs given below are not as surprising as they have been given above for Kilby. Nevertheless some of the details of Noyce's invention also have not been covered in the literature properly. Some of the key points of Noyce's invention are summarized as follows.

7.1. There is no controversy about the filing and issuance of the key patent to Bob Noyce for his invention of the IC. Late Bob Noyce, or perhaps more appropriately his patent attorney, late John Ralls who was the chief architect to write his patent, says it all regarding the invention in the very first paragraph of his patent. He had specified all the key processes and materials required for fabricating the monolithic-ICs, in particular the planar technology with silicon (Si), and the monolithic interconnects of aluminum (Al) adherent to the oxide layers. He had described p-n junction isolation in his patent and it was used in the reduction to practice of his invention, but he did not claim it. I have discussed the latter point with Sah [69] and I have given the technical reasons in Chapter 6 for why Noyce may not have claimed the p-n junction isolation in his patent. Noyce's patent describes essentially how the monolithic-ICs are still made with silicon, although most of the processes and materials used currently are much different and more advanced than those given originally.

7.2. Noyce was the top boss at Fairchild, which of course meant that everybody else including Moore, Hoerni, Last and the others were working for him. Noyce's invention and its patent were based on the disclosure in his notebook which was not witnessed. Some of his co-workers had felt that he had usurped their contributions which had made the ICs a reality, and that Noyce had written in his notebook in a hurry to claim it all himself.

7.3. Noyce had used Hoerni's invention of the planar technology and Lehovec's invention of the p-n junction isolation, but did not acknowledge them in his patent. The issue of the sole inventorship of the planar technology by Hoerni has been discussed briefly in section 3 above. To repeat, Hoerni had combined all the information from the work of the others elsewhere earlier than him and at Fairchild, several engineers and technicians other than Hoerni reduced his invention to practice, but Hoerni filed and received his patents to claim the planar technology invention. This is another mystery added to the saga of the invention of ICs by Kilby and Noyce which has also not been discussed before in the literature. However, its details are discussed in Chapter 6.

7.4 The reduction to practice of Noyce's invention was accomplished by several others under his direction, in addition to his own contributions in the design and construction of the step-and-repeat camera.

The sole credits for their respective inventions, coupled as the only two co-inventors of ICs, have been bestowed to Kilby and Noyce for all these years in the technical and popular literature. The above points regarding their invention clearly warrant clarifications of what actually their contributions were, and what did they actually invent? Much of the information perpetuated all this time for more than four decades, has been misleading and gives a distorted view of who did what? Additional incongruous events have accentuated the mystery which needs unfolding by incontrovertible documented and other facts from credible sources.

8. Other Contributors

Efforts other than those of Kilby and Noyce to invent the ICs shall also be described briefly in this book. There were several other inventors and contributors who had given their concepts for the invention of ICs earlier than Kilby and Noyce. It is rather unfortunate that an accurate and a thorough account of their contributions along with Kilby's and Noyce's, has not been published previously by the other experts and scholars in the microelectronics industry, academia and patent law. I have published a few papers recently which give the issues and facts of the inventions of ICs by Kilby and Noyce. I could describe the roles and contributions of the others to the invention of ICs only briefly in them, because of the limitation in the length of my papers imposed by the publishers. However I shall describe them in more detail in this book. For example, Geoffrey Dummer in England, Harwick Johnson of RCA and Richard Stewart also of Texas Instruments (as Kilby was from there too but joined TI later) right here in the USA, had described the concept of fabricating multiple devices within a single piece of semiconductor earlier than Kilby. I shall provide appropriate documents of Dummer (published papers), Johnson (patent) and Stewart (patent) for this purpose.

Even though I had published a paper in 1953 based on which I had also given the concepts for ICs independent of and earlier than Kilby and Noyce, I shall not discuss them in the main text of this book. I shall only refer to them in some relevant comparisons. However following Gordon Moore's sage advice (see Section 11 below), I shall defer giving details of my concepts to Appendix 2 for the sake of completeness of the historical record. It provides the available documents and discusses briefly what actually my contributions were. Appendix 1 also gives a brief summary of my contributions and patents in various fields of physics and microelectronics from 1953 onwards. They will also serve as a background for where I am coming from in writing this book.

I have discussed briefly in my earlier published papers why the previous writers of the history of invention of ICs may have had difficulty in giving a complete and accurate description. This is because the facts of the invention of ICs are intricately entwined technically, chronologically, and legally patent wise. To understand them, it is critical to know what are monolithic-ICs which are the only kind sold from the beginning in the IC industry, and how do hybrid-ICs differ from them. This apparently continued to be a bone of contention with Kilby even until later years in his life. The details of all the facts and their discussions are given in the various chapters of this book to unravel all the complexities. An exception to the Si monolithic-ICs which have also been sold in the recent years are the microwave ICs (e.g., in cellular phones and other products) which use both Si monolithic-ICs and ICs made from compound semiconductors packaged together by hybrid techniques.

To re-emphasize, Kilby's invention was not a Si monolithic-IC, the only kind sold from day one in the huge Si IC market. (Please note the exception to this in the previous paragraph regarding the microwave ICs.) Kilby's invention was a hybrid-IC. He did give some of the concepts but only in a very limited manner which could be applicable for the monolithic-ICs. Noyce's invention was complete but he had used others' (Hoerni, Lehovec) inventions for fabricating the monolithic-ICs, and it was not reduced to practice by him; it was done by his co-workers. There were no irregularities in the processing of Noyce's patents. But in Kilby's case, there were some irregularities in the filing, processing and issuing of his patents by the USPTO. The Nobel Prize awarded to Kilby did not specify what was his part to invent what kind of IC? It is rather perplexing why all the documented facts have been overlooked so far for the past five decades by the various experts?

9. Lack of contributions of Kilby and the others to pursue monolithic-ICs

Another important fact proven by the published records is that neither Dummer nor Stewart or Johnson had pursued the development of ICs further after disclosing their respective versions of the original concepts, even after Noyce's patent disclosing the monolithic-ICs had become public knowledge. This is important, because "diligence" is one of the key factors to claim an invention. The other is "reduction to practice" which is also important but not considered mandatory. It is not required that the inventor must reduce to practice his or her original invention; it may be done by the others working with the inventor. Still another important fact is that after receiving his patents on ICs, Kilby continued to regard the monolithic concept as controversial and made little if any contributions to the monolithic-ICs. The Nobel Prize awarded to Kilby "for his part in the invention of the integrated circuit" in 2000 is rife with controversy regarding what was his part in inventing which kind of IC. To a casual reader but with the knowledge of prior Nobel Awards, the double financial awarded to Kilby than to his co-winners Allferov and Kroemer would come as a surprise. I have offered an explanation for this unequal award, even though the Nobel Committee refrained from doing so. Even more striking fact is that neither Lehovec nor Hoerni contributed to the advancement of monolithic-ICs after their respective pioneering inventions crucial for the invention of ICs were patented. To be specific, Lehovec left the Sprague Electric Company and became a professor at University of Southern California (USC). He obtained several patents and published several papers mostly in areas other than in advanced ICs. However, Lehovec did publish a few rejoinders to Kilby's papers which had misinterpreted Lehovec's claims in his patent. Lehovec essentially left the science and technology field and became a poet and a philosopher, and has published a few books on the collections of his poetry. Hoerni started a few semiconductor companies after leaving Fairchild, but they did not become major corporations such as Intel or AMD in Silicon Valley.

10. Historical Perspective and Accuracy

Times and conditions change, therefore, an accurate account of the historical events in the invention of ICs necessitates that it must be given from the perspective of when they had taken place. The account should not be a descriptive hindsight or "Monday morning quarterbacking". Of course some aspects of hindsight will benefit the narrative of the progression of events as they had occurred, but they must be documented with published records and inputs from the key participants during these events. This is not an easy task for a conventional science history writer who perhaps maybe qualified and a skillful writer, but did not live through the entire period to participate and experience first hand most if not all the events as they had occurred and evolved. This may be the reason why none of the history writers have succeeded so far to give a comprehensive account accurately. Even the fragmented accounts in bits and pieces published by several authors have not given the facts correctly about the invention of ICs.

Wrong information is easy to contend with in proving their falsehoods, but misleading information is akin to half-truths and it is much more difficult to clarify and perhaps impossible to rectify its damage. Nevertheless the misleading information must be corrected and the truths must be uncovered for the sake of posterity. Our future generation must not be disillusioned about the events of the past. They must feel inspired to achieve their maximum potential and continue to make the future innovations for the benefit of mankind. The spin meisters may succeed in presenting what is white as black and vice versa temporarily, but the truth has a way to emerge eventually, especially in the technical and scientific fields. Thus, the very purpose of this book is to present the history from the positive point of view to document the truth of the invention of IC.

For the sake of convenience of all the readers, especially the scholars, I shall give in this book some of the key original patents and papers which may not be easily accessible to some of you. I shall also analyze each claim of a few of these patents which, to the best of my knowledge, have not been published before. Nevertheless these analyses and interpretations of the claims are strictly mine, so I regret sincerely if some errors and omissions may have crept in unwittingly.

Further, I shall not only give all the facts comprehensively in this book to prove unequivocally within their realm who invented what in ICs, but I shall also present a few questions at the end on the invention of ICs. Surprisingly they have remained as yet unanswered even after 48 years since Bob Noyce's patent was issued in 1961, and the IC invention had become public knowledge. I hope that all the readers, experts and laymen alike will find the pedantic historical accounts given here to be educational and thought provoking as well. The latter is particularly interesting when one realizes that many a participant (technical contributors as well as non-technical contributors), who have played key roles from the inception and during the progression up to the ULSICs, have remained silent rather than to publish and set the records straight earlier. The silence on the part of some may be understandable if they did not have first hand knowledge or if they were not involved directly in the various key events.

I have given all the facts in this book based on the various documents I could obtain so far, which is more than ever done before in the literature. However, I will concede at the outset that some of these facts may still be incomplete. As an example, despite my best attempts to get the case history files of Kilby's and Noyce's patents from the US Patent and Trademark Office (USPTO), I have not yet been able to get them so far. (See Chapter 15 on Conclusion.)

As it is well known, the business volume of ULSICs currently is in the range of multi-hundred billion dollars feeding into the systems market of several trillion dollars per year. Several of these participants have also parlayed and amassed huge fortunes, which is almost unparalleled in the entire business history of the world. It is natural for the entire society to expect them to publish and document the facts that they were privy to during these exciting years. Or they should at least speak up and correct the wrong information which had been given about the key inventions for more than four decades. But why haven't they done so? This fact adds to the unanswered questions which are discussed in this book.

11. My Experience

The readers may be curious about who am I and what are my qualifications to interpret and correct the history of one of the most important invention which has changed mankind forever? I shall describe them below briefly, and I have summarized my experience in Appendix 1. In the main text of this book, I have attempted to give all the relevant documents available for the invention of ICs by Kilby, Noyce and several others in this book, and analyze them thoroughly. For the sake of completeness of the historical record, I have also included the concepts of ICs given earlier by me. However, instead of giving them in the main text of the book, I have given the available documents in Appendix 2 at the end of this book. They have been written following the sage advice given to me by Gordon Moore, "On the part relating to your early insight you should do whatever you think is appropriate. ... I think that your job is to distinguish your insight from what others saw as the potential." My objective is to do just that when I give my concepts of ICs in Appendix 2. I think that it is appropriate to at least document them and give the relevant comparative information to distinguish my insight from the others, not coming as a hindsight but as it occurred originally in time and as it progressed. (See the original documents and papers in Appendix 2.)

I shall quote another statement by Gordon Moore from his paper, "I had the good fortune to be part of this important chapter in semiconductor history and would like to take this opportunity to record some of my recollections." Dittoing this statement, but more humbly, I wish to state that I was also among the lucky ones who had joined during the early years of Fairchild Semiconductor co-founded by (listed alphabetically) Julius Blank, Vic Grinich, Jean Hoerni, Gene Kleiner, Jay Last, Gordon Moore, Bob Noyce, and Sheldon Roberts. I had the distinct privilege of knowing them all personally. At Stanford, I had received the single crystals of Si from Texas Instruments in 1956-57 before Jack Kilby had joined it in 1958.

Let me give a brief historical account of the start of Shockley Semiconductor Laboratory of the Beckman Instrument Corporation in Mt. View, CA, which is relevant to when did Bob Noyce, Gordon Moore et al start to work with Si in this laboratory. Arnold Beckman and Bill Shockley held a news conference on February 14, 1956, to announce their plans to start the lab [71]. At the suggestion of John Linvill, a professor at Stanford University, Shockley rented a dilapidated building at 391 South San Antonio Road, Mt. View. It needed a lot of work to make it suitable for the work he and his colleagues wanted to do in his laboratory. He announced at the March meeting of the American Physical Society in Pasadena that he was hiring. Shockley hired Bob Noyce, Gordon Moore, and the others rapidly. The work was started around April, 1956. Shockley Semiconductor Laboratory of the Beckman Instrument Corporation later became the Shockley Transistor Corporation. Shockley, Noyce, Moore, et al had started to use Si a few months earlier than I did. They had used it for making devices, but I had used the single crystals of Si for my PhD research in 1957 at Stanford (see Appendix 1).

For whatever it is worth, I have also published in the topmost journals such as the Physical Review, Physical Review Letters, and Proc. Phys. Soc. (London), and others. I had not only participated in the exciting events originally in the Silicon Valley and later too, but I was not confined to it. I have also worked in the East Coast of US, and in Europe, and interacted with several key personnel in other countries including Japan, Taiwan and Korea. Further, I have worked in both the corporate and academic sectors of the business, and also interacted with the government sector. Therefore, I have a global perspective on the invention of ICs and their future developments.

12. Useful Product

Another key observation I have is that unless an invention can be converted into a useful product, which can be commercialized successfully, it may be the most wonderful discovery, but at best it will be destined to remain in research journals and text books only. The inventors of the transistor won the Nobel Prize, but they were not successful to reap the harvest of their invention. However, Bob Noyce put two and two together with the invention of the planar transistor, co-invented the monolithic-IC, led a highly motivated team including Gordon Moore and several others, and commercialized it. It grew and advanced rapidly into the hugely profitable business of ULSICs consisting of many successful corporations in the world. I was very fortunate indeed to have been associated with Bob Noyce, Gordon Moore and the others in the early years.

13. Funding for putting all the facts of the invention of ICs on historical record

Unlike several of the other authors who have written about the Invention of ICs, I would like to state up front that I have neither solicited nor received any financial support from various sources to write this book. All of the facts presented by me about the invention of ICs in this book are well documented and available in the public domain. I have, however, also used the inputs on the invention of ICs from a few key individuals which have not been published before. In this regard, I have used my judgment and professional discretion not to disclose some of their names. However in most such cases, I have the inputs shared with me in writing, e. g., via letters and e-mails. My aim is to put all these facts of the invention of ICs on historical record, and interpret them objectively and accurately to bring out the truth as an insider to this whole saga of their birth and progression to the ULSICs. The fervent desire to get history right for the benefit of everyone: all professionals, laymen and laywomen, especially the younger generation, has helped me in overcoming many an impediment, disparaging moments, even portentous reactions and diatribe.

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