Semiconductor Device to Take a Quantum Physics Leap

Glamorous charm of Internet of things renders little attention on the core driving force - semiconductor technology. Just like flashing Ferrari sports car, only engineers (not even physicists) care for the engine. There is, however, really no comparison. The microprocessor of information appliances has been leaping and bouncing with a mind-boggling rate of 100x in every 7-8 years for the past 40 years and going. To have a feel, application processor inside a smart phone today has the supercomputing capability just 15 years ago (~10^{11}) and supercomputer performance is expected to approach exascale (10^{18}) in 5 years. Semiconductor is powering endless innovation and imagination of the future.

As engineers are driving to reach the next semiconductor milestone while people get enchanted by Internet of things, there is an unprecedented challenge lurking ahead, only recognized by semiconductor visionaries. Although false claims of the end of semiconductor scaling were reported and ridiculed in the past, its time is inevitably coming due to atomic limitation where Quantum Mechanics rules. According to the International Technology Roadmap for Semiconductors, 10nm technology is into production in 2015 and 7nm, 2017, and it is generally believed that wave characteristics start to dominate in semiconductor when size is smaller than 10nm. For the past >half century, semiconductor device physics have been accurately modeled by semi-classical Shockley Equations, which are wonderful for describing the behavior of electrons and holes. With the advent of atomic limitation, unfortunately, these equations become insufficient due to Quantization effects of nanoscale structures. Schroedinger equation must be applied to solve carrier transport while considering phonon interaction since devices operate in room temperature. The problem becomes so convoluted that it seems hopeless for intuitive imagination which is vital for inventing nanosemiconductor devices and finding engineering solutions.

To make the matter worse, little interest in semiconductor is expressed by electrical engineering undergraduate students who avoid taking fundamental physics curricula such as Modern Physics, Quantum Mechanics, etc. If the situation persists, future semiconductor engineers are likely to have difficulties in understanding issues in nanoelectronics, let alone finding solutions. With this background, I sincerely plead to physics community for your participation in promoting semiconductor education and research in campus. The technical challenge is no doubt at Nobel Prize level and potential contribution to mankind is at the similar significance as that of transistor invention by Shockey, Bardeen, and Brattain in 1947, and also integrated circuit by Kilby and Noyce' in 1958.

Albert Einstein once said "If I had only one hour to save the world, I would spend fifty-five minutes defining the problem, and only five minutes finding the solution" and he also said "Concern for man and his fate must always form the chief interest of all technical endeavors. Never forget this in the midst of your diagrams and equations."Explosive growth of information technology rides on semiconductor innovation as depicted by Moore's law for almost 50 years. Although geometry scaling inevitably ends at nanoscale dimensions, novel transistors based on Quantum Physics will carry mankind into future world.

半導體元件即將跳進量子領域

只要與Internet有關的事物都散發出光彩奪目的魅力。然而，卻很少人關注推動它的原動力 – 半導體技術。就像亮眼的法拉利跑車，只有工程師(甚至不是物理學家)會對它的引擎有興趣。但是，相較於微處理器的演進，汽車引擎真的是沒的比。微處理器的功能，在過去40年中以令人難以置信的速度成長，每7-8年增加100倍。舉例來說，現今任一款智慧手機內的應用處理器，它的計算能力已達到15年前的超級電腦水準（10^{11}），而超級電腦有望在5年到達每秒百億億次計算的性能（10^{18}）。對於未來，半導體不斷地提供人類創新和想像的動力。

當人們陶醉在Internet中，半導體工程師正在為完成下一個技術里程碑做努力。此時，半導體先進們預測了一個前所未有的技術挑戰，潛伏在不久的未來。雖然，類似的警告曾多次在過去被提出而又被推翻，這早已成為茶餘飯後的嘲諷話題。然而，這一次的預測很可能是真的。因為半導體元件即將進入數十原子大小，在這微小的尺寸中，只有量子力學能正確描述載子行為。根據國際半導體技術發展藍圖，10nm及7nm技術將分別於2015年和2017年的投產。一般認為量子波動特徵在半導體尺寸小於10nm時，逐漸主導載子行為。在過去逾半世紀以來，半導體元件中electron和hole的物理行為可以被Shockley Equations精確地描述。不幸的是，隨著納米結構接近原子大小，這些方程式不足以正確描述量子行為。這時必須應用Schoedinger Equation才能了解載子輸運，而且同時必須考慮到在室溫下操作下的聲子相互作用。這個問題就變得異常複雜，而直觀的想像量子行為，似乎不可能。然而，這直觀的想像對於發明nanosemiconductor元件和尋找工程解決方案而言，是至關重要的。

更糟的是，電機工程大學生對研究半導體興趣缺缺，也迴避修技術的挑戰習基本物理課程，如現代物理學，量子力學等。如果這樣狀況持續，未來半導體工程師可能有困難理解納米電子問題，更不用說找到解決方案。在這種背景下，我懇請物理學界教授們參與推動半導體的教育和研究。我們面對的是諾貝爾獎級的技術挑戰，而其對人類的潛在貢獻是毫無疑問的。我們可以從1947年Shockley, Bardeen 和Brattan的電晶體發明，與1958年Kilby和Noyce的積體電路發明，得到驗證。

愛因斯坦曾經說過:“如果我只有一個小時來拯救世界,我會花55分鐘來定義問題,只有五分鐘來尋找解決方案”，他也說：“對人類及其命運的關注，始終是一切技術努力的焦點。在你的圖表和公式之中，永遠不要忘記它的存在。“摩爾定律所描述的半導體技術的創新，為近50年來訊息技術帶來了爆炸式增長。雖然，不可避免地，幾何縮放將結束於納米尺寸，然而源於量子物理學的新型電晶體將攜帶人類進入未來世界。