Professor J.C.H. Phang (1953-2013), Scientist and Technopreneur

Our community recently lost one of its "movers and shakers:" Jacob C.H. Phang, professor at the National University of Singapore and Chairman of SEMICAPS Pte Ltd., Singapore. In this issue, we pay homage to Professor Phang, congenially referred to as "Prof" by his students. Dr. David Tan of SEMICAPS Pte Ltd. has written a tribute to Jacob (see page 26 in this issue), which accompanies an unpublished column by Jacob Phang on his contributions to the development of scanning optical microscopy (SOM) for the semiconductor industry.

I had the privilege to collaborate with Jacob since the late 1990s. While I was at Advanced Micro Devices, we co-developed a SOM specifically for such new backside techniques as soft defect localization and other laser-intrusive techniques that were rapidly being developed for backside analysis during that dynamic period. This is described in further detail in Jacob's last column, published on page 28 in this issue. As a result of this collaboration, Jacob and I published several papers and gave many joint seminars/tutorials on laser-induced techniques. Jacob won many prestigious awards in his lifetime, as detailed by David Tan's article, but I want to emphasize his contributions to the Electronic Device Failure Analysis Society (EDFAS) and his legacy.

Jacob was a prolific contributor to EDFAS, having served on many committees including the *EDFA* Editorial Board, published five articles in *EDFA* magazine, and, by my estimate, published at least 27 articles at the International Symposium for Testing and Failure Analysis (ISTFA) spanning the period 1994 to 2011.* He won two Best Paper Awards at ISTFA: one in 2000 for his single contact optical beam induced current technique (M. Palaniappan et al., ISTFA 2000, p. 17) and the other in 2008 for applications of near-field photon emission microscopy (D.V. Isakov et al., ISTFA 2008, p. 25). In addition, a Best Paper from the International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA) on using a solid immersion lens to enhance laser-induced fault isolation techniques was presented at ISTFA 2008 (S.H. Goh et al., ISTFA 2008, p. 1).

The breadth of Jacob's research was immense, covering a diverse range of topics related to failure analysis: scanning electron microscopy, backside analysis, device physics, solar cells, cathodoluminescence, thermal microscopy, photon emission microscopy, scanning optical microscopy, near-field microcopy, laser timing probe, static and dynamic laser stimulation techniques, solid immersion lens, and much more. As a scientist and teacher, he took the time to understand the principles behind a technology, all while mentoring students. However, what is rare was his ability to move out from academia and bring a concept from the lab to market through the benefit of his in-depth understanding. He often referred to this as "technopreneurship," a technically savvy entrepreneur.

Everywhere I go, I run into Jacob's former students all around the world.

He leaves a legacy of students and colleagues who will continue his values and principles: a can-do spirit for tackling "big, hairy, audacious goals" and "finding ways to make 'dents in the universe.'"**

One thing I have learned about EDFAS is that it is a true community. We all mourn when we lose a valued member of a community. Jacob will be sorely missed by all, but especially by me, as it was an honor and a privilege to have worked with him.

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*I thank Ann Britton of ASM International for assistance in researching Professor Phang's ISFTA articles and awards. A search on J.C.H. Phang at scholar.google.com yields 1470 hits (accessed May 21, 2013)!

**http://e27.co/2013/01/09/noc-alumni-remembers-professor-jacob-phang (accessed May 22, 2013)

Letters to the Editor: *EDFA encourages your participation. Send your comments and suggestions to Mike Bruce, EDFA Editor, at mike.bruce@earthlink.net.*

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Tribute to Jacob C.H. Phang

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2009 Singapore President's Technology Award—Jacob with his winning team. S.H. Goh (1st from left) and Alfred Quah (2nd from right) are now with Globalfoundries. S.H. Tan, C.M. Chua, L.S. Koh, and W.P. Chua are with SEMICAPS.

Jacob C.H. Phang passed away in January of this year after fighting lung cancer for nearly three years. During his working career, up to days before his death, he was actively involved in the semiconductor failure analysis field.

Jacob was born in 1953 in Singapore and graduated from the University of Cambridge with a B.A. degree in 1975. He obtained his Ph.D. from the same university in 1979, working on scanning electron microscopy (SEM). He then joined the National University of Singapore (NUS), where he remained until his passing.

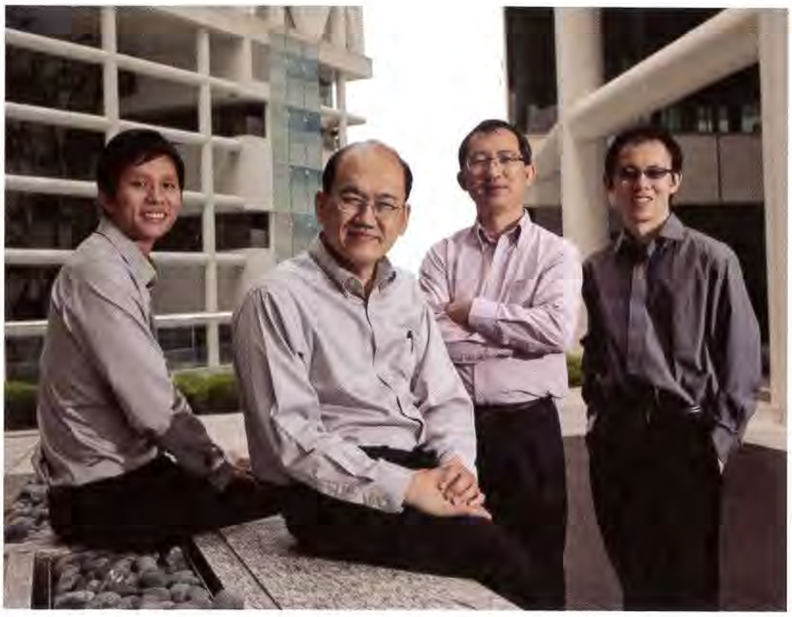
Semiconductor failure analysis remained Jacob's primary interest in his work, spanning over 30 years. This started with his Ph.D. work on SEM but extended to areas such as voltage contrast, scanning electron acoustic microscopy, electron-beam-induced current technology, and cathodoluminescence. In the 1990s, Jacob became interested in using photon emission microscopy and laser scanning microscopy for semiconductor fault localization and defect characterization.

Jacob was a founding member of the Centre for Integrated Circuit Failure Analysis and Reliability (CICFAR) at NUS, and he was also actively involved in an advanced solid immersion lens (SIL) project that aims to design an SIL for backside semiconductor analysis with a spot size well below 100 nm.

Life as a technopreneur started for Jacob when he founded SEMICAPS in 1988 with colleagues to commercialize an image capture, enhancement, and storage system for the SEM. This was a boon to SEM users back then, because it allowed them to store their SEM images digitally instead of using Polaroid photographs.

With the advent of digital SEMs, interest shifted to semiconductor fault localization, where Jacob and his collaborators implemented soft defect localization and a pulsed laser technique on their laser scanning microscopes. More recently, laser waveform probe equipment with an aplanatic SIL was developed. The use of this machine has been successfully proven for the 22 nm node by a large customer. Another pioneering tool is a direct-dock analytical wafer prober that allows dynamic laser analysis of dies on a wafer, avoiding the need to sort and package the dies before analysis. A leading foundry was able to use this machine to land more than 5000 pins using a normal commercial probe card.

Besides his research and business activities, Jacob was also involved in university administration at NUS. Worthy of mention among these is an organization he helped form: NUS Enterprise. Up to the turn of the century, the mindset of almost all technology (both engineering and biotech) students in Singapore was not very entrepreneurial. When polled, more than 90% would say that they prefer to work for the government or a large corporation. NUS Enterprise was set up to change this, with Jacob at the helm to impart his experience from SEMICAPS. Besides looking after a business incubator, a technology management office, a seed fund, and other activities, Jacob started an attachment program for selected students to intern at technology companies and startups in overseas regions such as the Silicon Valley while attending courses at a prominent university there. The former students from this scheme have developed into a strong network of 1000 alumni.



Jacob with his team of former students, winners of the 2009 President's Technology Award presented by Singapore. From the left, Dr. S.H. Goh (Globalfoundries), Jacob, C.M. Chua (Semicaps), and Dr. Alfred Quah (Globalfoundries)

One of them, K.F. Tay, the founder of brand consultancy Tangible, wrote of Jacob, "I also remember him always asking, 'What's next?' To us, it was a start-up-experience-cum-Stanford thing, but to him, it was always about 'big, hairy, audacious goals.'"

Tay added: "... I suppose he'd be glad to know he's succeeded in his work to create a generation of entrepreneurial-minded people who are constantly finding ways to make 'dents in the universe.'"

"He never took status quo as satisfactory and constantly challenged it to see how it can be better. Maybe it's something everyone is used to now, but back in 2002, when the entrepreneurial mindset was new, it was liberating to know we can change anything we don't like."

One emerging startup from this program is tenCube, which provides mobile phone security and was bought by McAfee in 2010.

Jacob was also a caring supervisor to his research students. He was supportive of their participation in international conferences, sometimes at his personal expense. He remained engaged with their research work until his final days. When he was too unwell, he would welcome students at home to discuss their projects.

Jacob served as the Section Chairman, IEEE Singapore from 1986 to 1987 and was among the founding committee members of IPFA in 1987.

In 2002, Jacob was bestowed the title of "Chevalier" in the order of "Palmes Academiques." The honorary conferment, rarely given to foreign scholars by the French government, is in recognition of Jacob's sustained efforts in the improvement of France-Singapore relations in the area of education and research. In 2009, Jacob was awarded the President's Technology

Award by Singapore in recognition of his team's efforts at NUS and SEMICAPS for "their outstanding contributions to the research, development, and commercialization of scanning optical microscope systems for design debug and failure analysis of advanced integrated circuits."

An homage published by the *Straits Times*, Singapore's main newspaper, cited a tribute from 50 friends from his old Cambridge days, where he was an active student leader. These friends included Singapore's current Prime Minister Lee, Minister for Trade and Industry Lim, and the former Foreign Minister Yeo. They hailed him as an engineer, entrepreneur, mentor, and generous friend.

In a personal e-mail, Professor Cary Yang from Santa Clara University wrote, "Jacob's passing is a huge loss for the scientific community and undoubtedly for Singapore. For as long as I knew Jacob (21+ years), I have told numerous friends and professional colleagues that Jacob is what Singapore is all about: entrepreneurial, enterprising, down-to-earth, and, above all, an eminent scholar and a great person. It is tragic that the world lost Jacob at such a young age."

Jacob is survived by his wife Jennifer and their four children.

**This column, written by Jacob Phang in 2009, was edited for this tribute section by Mike Bruce, EDFA Editor, in 2013.*

Research, Development, and Commercialization of Scanning Optical Microscope Technology for Failure Analysis of Advanced Integrated Circuits*

Jacob C.H. Phang, Professor, Centre for Integrated Circuit Failure Analysis and Reliability (CICFAR), National University of Singapore; Executive Chairman, SEMICAPS Pte Ltd., Singapore

When *EDFA* Editor Rose Ring suggested that I write a column for *EDFA* to describe our contributions to ISTFA from 1999 to 2008 to commemorate the tenth anniversary of EDFAS, I took the opportunity to look through the 17 papers that the research group at the Centre for Integrated Circuit and Reliability (CICFAR) of the National University of Singapore (NUS) and the research and development team at SEMICAPS Pte Ltd. published together with our collaborators during this period. Although we have been involved with various FA techniques, such as scanning electron microscopy, photon emission microscopy, scanning thermal microscopy, and so on, this column attempts to summarize the research, development, and commercialization of scanning optical microscope technology for backside failure analysis undertaken by our research group and our collaborators during the last ten years.

It was coincidence or serendipity that the beginning of *EDFA* in the late 1990s was also the time when we had to switch from electron beam technology to near-infrared optical technology to pursue research on backside techniques. Frontside failure analysis had become impractical due to the growing use of multilevel metals and array input-output connection pads across the die for higher-speed devices. In 1997, research on backside failure analysis techniques began at CICFAR under the codename FABRIC, which was the acronym for Failure Analysis of Backside Regions of Integrated Circuits. In 1999, this work received a major boost with significant funding from an AMD-NUS-SEMICAPS collaboration to research and develop a scanning near-infrared optical microscope system capable of backside thermal stimulation and carrier generation for active fault localization. In the following twelve months, AMD and SEMICAPS engineers worked together to design and develop an analytical platform capable of delivering a scanned focused 1064 nm and 1340 nm laser beam for active

(continued on page 30)

Tribute to Jacob C.H. Phang

(continued from page 28)

fault localization of packaged devices. This resulted in an upright scanning optical microscope (SOM) system developed in August 2000, with the first system installed at AMD Austin[1] and AMD Singapore,[2] which helped facilitate further development of fault localization techniques.

At the same time, NUS researchers with AMD and SEMICAPS engineers researched ways to improve the detection sensitivity of laser-induced techniques. A new detection method incorporating a novel circuit that translates current-change detection to voltage-change detection in combination with precise dwell-time control, laser pulsing, and lock-in amplification allowed more than an order improvement in detection sensitivity over other previous detection methods.[3] A Spansion-NUS-SEMICAPS collaboration established the basis for the application of the SOM techniques to flash memory defects, which was presented at ISTFA 2004.[4]

Jacob Phang receiving the ISTFA 2000 Best Paper Award. Left to right: Dan Barton, Glen Gilfeather, Jacob Phang, and Dick Ross

In the previous analytical configuration, the tester connection to the device under test (DUT) is established via cables, which typically have a speed limit of 100 MHz. To test DUTs while running at full speed, an upright tester-dockable SOM system was developed that allowed direct docking with automated test equipment (ATE). This development required a basic understanding of the vibration characteristics of the tester and test floor and the resonant frequencies of the various components in the SOM system, together with a comprehensive optimization of the vibration characteristics of the system through extensive measurement and simulation. These issues were investigated in a separate collaboration between SEMICAPS and the NUS Mechanical Engineering Department and resulted in a direct-docking strategy that limited the resolution degradation of the tester-docked SOM to less than 20%. This methodology allows a paradigm change in the way high-resolution analytical instruments and ATE testers work together. In 2004, an inverted tester-dockable SOM was developed with another partner to accommodate large test heads. It is now the most common type of SOM system used in production test areas. In 2005, collaboration was undertaken with a foundry partner to develop a SOM system with 300 mm wafer-handling capability. This configuration was used for both tester-docked applications and analytical applications with 300 mm whole wafers, wafer parts, and packaged devices. In 2008, SEMICAPS collaborated with another foundry partner to develop a wafer prober that can be tester-docked with wafers for automated backside die-to-die analysis for yield-enhancement applications. The research and development efforts have resulted in SOM system configurations that meet the diverse needs of design debug, product engineering, yield enhancements, and customer returns for integrated device manufacturers, foundries, fabless, and service companies.

The International Technology Roadmap for Semiconductors[5] has articulated that detection sensitivity and spatial resolution remain the key challenges for integrated circuit failure analysis techniques. This is an area where NUS and SEMICAPS have done extensive research and development. In 2006, the development was reported of a dc-coupled detector for laser-induced signals that overcomes the sensitivity limitations and artifacts present in ac-coupled detectors.[6] An additional benefit is the hitherto impossible capability of localizing large-area defects. An enhanced detection scheme with pulsed lasers without the use of lock-in amplifiers was developed.[7,8] This technique was used to localize copper/low-k reliability defects in collaboration with Nanyang Technological University and Chartered Semiconductor Manufacturing of Singapore.[9] Also, a voltage bias amplifier (VBA) detector, which allows voltage-bias and voltage-change detection, was developed. The combination of VBA with laser pulsing and an enhanced detection scheme provides high sensitivity for fault localization of shorts and opens based on laser-induced effects.

The current resolution of far-field optical systems is limited by diffraction effects to approximately 1 μm for a laser wavelength of 1340 nm. In 2004, a research program began to investigate the use of refractive solid immersion lens (RSIL) technology for resolution of far-field systems for backside analysis. A comprehensive theoretical and analytical framework was developed that allowed us to understand the effect of the various parameters that affect RSIL for backside imaging and SOM applications. The paper that describes this study was presented at the 2008 IEEE International Symposium on Physical and Failure Analysis of Integrated Circuits in Singapore. It won the Best Paper Award[10] and was presented at ISTFA 2008 as an invited paper.[11] Based on this study, an aplanatic RSIL was developed that can achieve a resolution better than 200 nm with a 1064 nm laser. Basic studies have also been conducted to understand the benefits of combining the resolution- and detection-enhancement techniques for fault localization. A collaboration with AMD Singapore in this area resulted in the laser-induced imaging of a single via from a 65 nm technology node device.[12]

In his paper entitled "Why Waste Time on Roadmaps When We Don't Have Cars?"[13] Dave Vallett recommended that the university research network be engaged in finding and funding new technologies for the semiconductor industry. Looking back at the past ten years of our research, development, and commercialization results involving university researchers, instrument developers, and industrial collaborators, I believe that we have already gone beyond Dave's recommendations.

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