The Love and Labour of a Laureate

Chinese University Bulletin

Special Supplement on Prof. Charles K. Kao

Former Vice-Chancellor and Nobel Laureate

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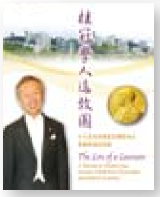


A minor planet (no. 3463) has been named after Professor Kao
as 'Kaokuen' in 1996 by the Purple Mountain Observatory of
the Chinese Academy of Sciences

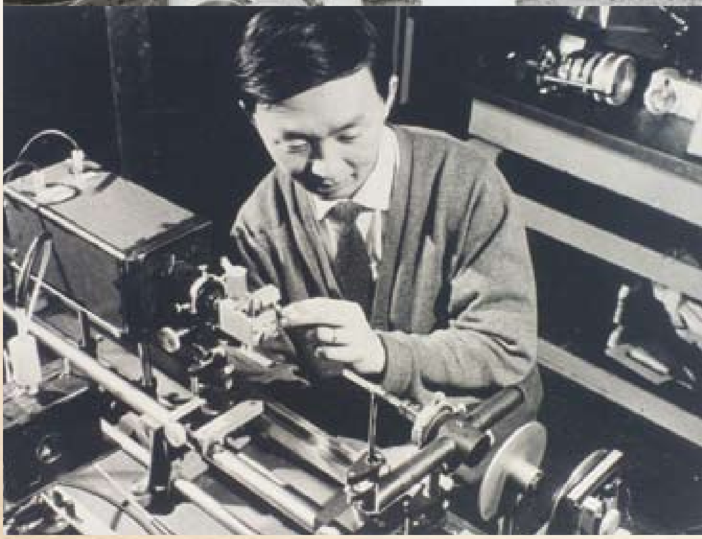
High-speed Internet, inexpensive long-distance phone calls, video-conferencing. Communication as we know it would not exist without Professor Kao's glass fiber cables. Not only did optical fibers revolutionize the way we connect with each other, they have changed our concept of time and space. 'Information at your fingertips.' 'The world at your doorstep.' 'Real-time connections.' In what to most people was the stuff of dreams half a century ago, Charles Kao saw the future. Other scientists and engineers contributed to the development of modern networks in the ensuing decades, but it was the 'master of light', as Kao is called by jury at the Royal Swedish Academy of Sciences, who made us a gift of the impossible.

Professor Charles K. Kao, former Vice-Chancellor of The Chinese University of Hong Kong, was awarded the Nobel Prize in Physics 2009 by the Royal Swedish Academy of Sciences, for his visionary work on the transmission of light in optical fibers.

Time present and time past
Are both perhaps present in time future,
And time future contained in time past.

T.S. Eliot, 'Four Quartets'

Almost all of today's telecommunication advances could be traced back to a lab in London where in 1963, a 30-year-old doctoral student at University College London developed concepts, made conjectures, began experiments that culminated in the proof for an idea as bold as it was imaginative—that light could travel long distances through cheap and plentiful glass, thereby transmitting huge amounts of data efficiently. In the 1960s, Standard Telecommunications Laboratory Limited (STL) in England, ITT's central research facility in Europe, was engaged in trying to achieve higher bandwidth using different carriers. Professor Kao strove to find a material through which light pulses could be guided, that is sufficiently transparent to be practical. He zeroed in on glass. Glass is made from silica—sand from the beginning of time, also the most abundant mineral on the Earth's crust. Fused silica melts at 2000°C, allowing itself to be teased into fibers, strong, light, flexible, and thinner than hair.



Top: Fresh graduate Charles Kao taking a picnic break during a car trip with classmates in England some 50 years ago

Below: Flashback to 1960s: the young scientist Charles Kao conducting an early experiment on optical fiber at Standard Telecommunications Laboratory at Harlow town, Britain

But there were obstacles and they were huge. One was getting a beam of light to travel from A to B. A torch shone at a window is visible on the other side, but one shone at glass 100 m thick would be lost in transmission. Professor Kao's conjecture was that the dimming of light passing through the glass fiber was due not to intrinsic absorption by the glass, but to impurities in it. Hence if the impurities could be removed, one should be able to see through a slab several hundred metres thick. That insight, which Professor Kao proved by careful measurements, ushered in the dawn of optical communications. Today it is possible for 95 per cent of the light to remain after having travelled a full kilometre in glass.

In 1966, Professor Kao presented his ideas at a meeting of the Institute of Electrical Engineers (IEE) and then wrote up the findings in a paper titled 'Dielectric-Fiber Surface Waveguides for Optical Frequencies', published in the *Proceedings of IEE* in July 1966. The date is now regarded as the birthday of optical fiber communication, but it had taken Professor Kao years to convince the world that a concept of such magnitude was in fact practical. In 1970, inspired by his enthusiasm, scientists at Corning Glass Works unveiled a fiber-optic strand that had the ability to carry a high-speed signal over 1 km. So the light came, and all shadow was dispelled between the idea and reality. And the rest, as they say, is history.

Looking into the future (Photo: South China Morning Post)

In 1970, the 'master of light' left ITT for illumination of a different nature—education. He founded the Department of Electronics at The Chinese University of Hong Kong. Then in 1987, he accepted an invitation to be the Vice-Chancellor of CUHK. Having grown up as a young boy who fashioned mud bombs out of red phosphorus powder and potassium chlorate, Kao was convinced of the importance of freedom and curiosity to academic creativity. He once said in an interview when asked what in his early life had sparked his interest in science, that he had been surrounded by people who were curiosity-driven, and they had learnt by reading and experimenting. That had opened their minds without the constraint of having had to follow a rigid course of study. He added that by being over-protective, parents limit the possibilities open to their children. Out-of-the-box thinking, he concluded, is extremely important.

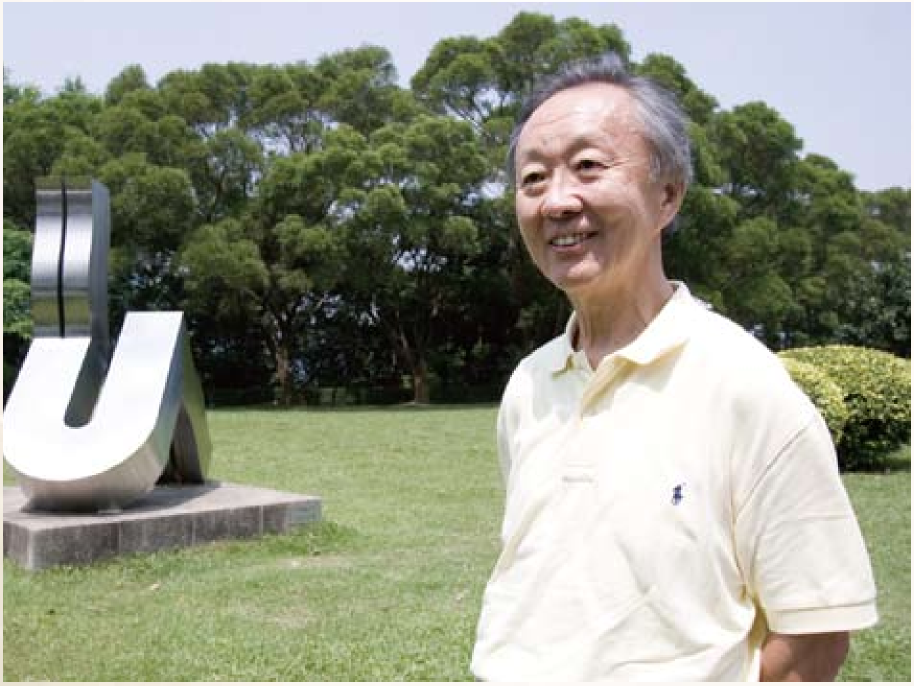
Top: Professor Kao at a welcoming party on his visit to Hong Kong as vice-chancellor-designate in May 1987. On his left are Mrs. Gwen Kao and Prof. Ma Lin

*Above: Professor Kao at Vice-Chancellor's lodge in 1988

Kao believed his role as the third Vice-Chancellor of CUHK was to create space for talent to grow, thus enabling the university to grow as a whole. No surprise, therefore, that under his leadership, research thrived at the University—research institutes proliferated in all disciplines, and a Research and Technology Administration Office was set up to render back-office support to academics. Interestingly, when asked which achievement had brought him the greatest satisfaction, Kao had answered that it was his having created 'a scholarly atmosphere on campus'. Like light fleeting through glass, atmosphere is elusive, yet its shimmering presence is only possible under the most precise conditions. Professor Kao retired in 1996, and to this day, is still fondly and reverently remembered for his legacy of vision and integrity.

Top: With Mrs. Kao at the ceremony for the presentation of the statue of Dr. Choh-ming Li, founding Vice-Chancellor of CUHK, in November 2004

Above: Shoulder to shoulder with students on the first day of the 1994–95 academic year



Prior to the Nobel Prize, Professor Kao had been bestowed a galaxy of honours, including the Charles Stark Draper Prize, the Japan Prize, the equivalent of the Nobel in that country, a Marconi International Fellowship, and the Alexander Graham Bell Medal by IEEE. Some may say the Swedish prize had come a little too late for the 76-year-old Kao, who was unable to deliver the Nobel speech himself. But what do we know of lucidity, we who had doubts while he was seeking the world's purest glass?


高錕樓
CHARLES KUEN KAO BUILDING

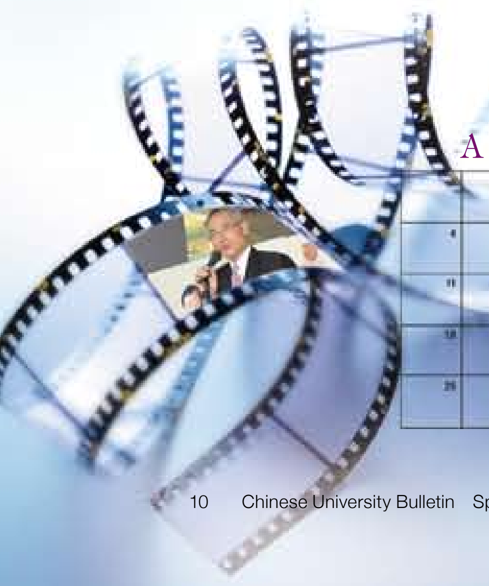
A Campus

Good News Sent Fast from Afar

On the evening of 6 October 2009, the news of Prof. Charles K. Kao, former Vice-Chancellor of CUHK from 1987 to 1996, receiving the 2009 Nobel Prize in Physics thrilled the Hong Kong community. All CUHK members felt privileged to share in the joy and honour. Later that night, Prof. Lawrence J. Lau, CUHK Vice-Chancellor, issued an open letter to members of the University, recapping the good news and extending our heartfelt congratulations to Professor Kao on behalf of the University.

'This is truly great news for The Chinese University of Hong Kong, for Hong Kong, for China, and indeed for all Chinese around the world...The high-speed network communication that is now such an integral part of modern living owes much to Professor Charles Kao, the trailblazer.'

— from the Vice-Chancellor's open letter



A Campus in Jubilation

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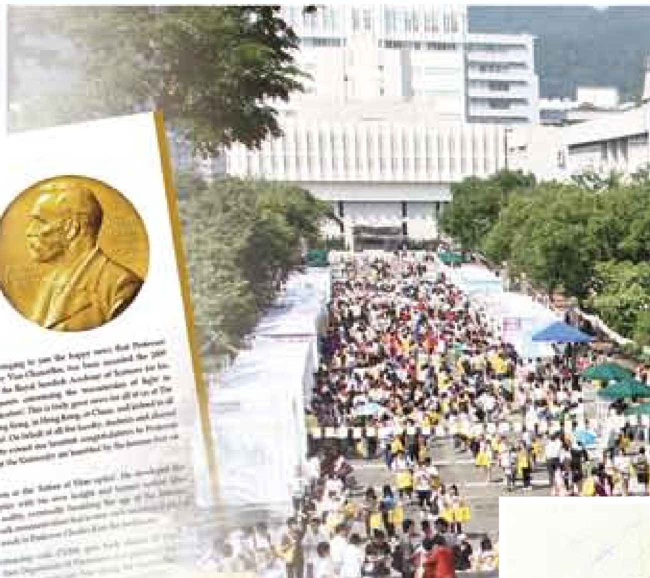
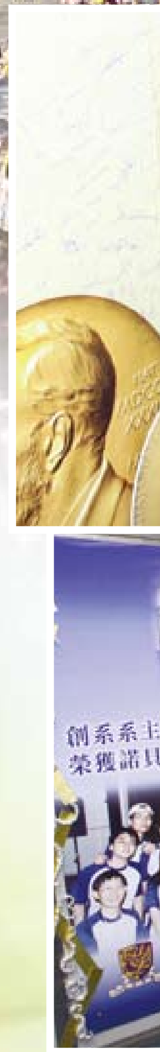
October 2009

in Jubilation

Congratulations from Across the Seas

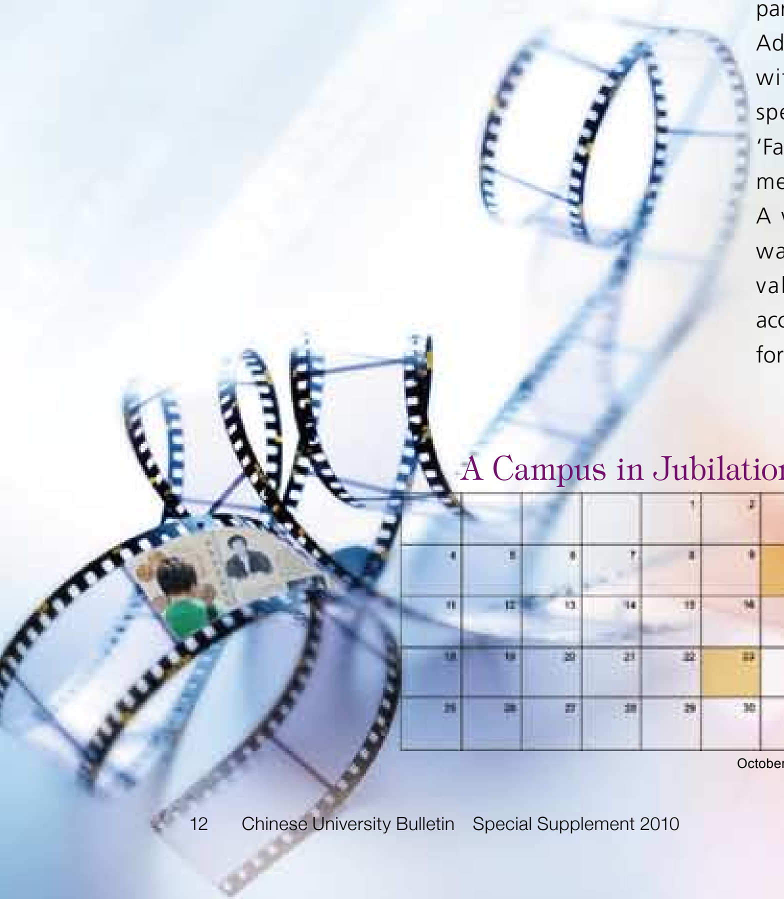
The University held a celebration the day after the Nobel Prize announcement. Many University members and guests including Professor Lau; Prof. Ambrose King, former Vice-Chancellor; Prof. C.N. Yang, Nobel Laureate in Physics 1957 and Prof. Andrew C.C. Yao, Turing Award Winner 2000—both Distinguished-Professors-at-Large at CUHK, spoke on the occasion and exchanged anecdotes about Professor Kao. The celebration climaxed with a photo-taking session, in which some 100 teachers and students toasted Professor Kao's achievements and sent their warm congratulations to Professor Kao.





Sharing our Joy with Visitors

The campus was visited by about 25,000 secondary teachers, students and their parents on the Orientation Day for Undergraduate Admissions held on 10 October. They browsed with deep interest exhibition boards set up specially to introduce the achievements of the 'Father of Fiber Optics'. Many left congratulatory messages on display boards to Professor Kao. A website (*www.cuhk.edu.hk/cpr/charleskao/*) was launched on the same day containing valuable information on Professor Kao, his accomplishments at CUHK, and a message board for the public to share their thoughts.



A Campus in Jubilation

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October 2009

'A Thousand Wishes' Signature Campaign

Over 1,000 warm wishes to Professor and Mrs. Kao swamped the website shortly after the launch of the 'A Thousand Wishes' campaign on 23 October by the CUHK Convocation. CUHK alumni from Hong Kong and all over the world chose the speediest way to convey their good will to the scientist who had made this instant communication possible.

Congratulations. Professor Kao changed our life. Best wishes for Professor Kao's family.

—from Mexico

'The impact, excitement and success of scientific research will go way beyond what a Nobel Prize means! You are always well recognized and respected in our hearts.'

—from California

Live Broadcast of Nobel Lecture on CUHK Campus and Website

Professor Kao's Nobel Lecture in Physics entitled 'Sand from Centuries Past; Send Future Voices Fast' was delivered on 8 December by Mrs. Gwen Kao in Stockholm, Sweden. To share this memorable moment with CUHK members and the public, the University broadcast the lecture live on campus and the Internet. An audience of around 300 including Vice-Chancellor Prof. Lawrence J. Lau, Pro-Vice-Chancellor Prof. Kenneth Young, and Prof. C.N. Yang gathered at T.Y. Wong Hall, Ho Sin-Hang Building to revisit the journey of optic communication development, aptly using the latest derivative of the technology.

Professor Kao (left) receiving from King Carl XVI Gustaf of Sweden (right) the Nobel Prize medallion and diploma (Photo: China Foto Press)

Professor and Mrs. Kao at the Nobel Banquet (Photo: China Foto Press)

Live Web Broadcast of Nobel Prize Presentation

On 10 December, the University arranged another live web broadcast, enabling the public to witness Professor Kao's moment of glory when he received the Nobel Prize at the Concert Hall in Stockholm.

'A Tribute to Prof. Charles Kao—Father of Fiber Optics'

Mr. Tsang Tak-sing (left), Secretary for Home Affairs, and Prof. Lawrence J. Lau, CUHK Vice-Chancellor, trying out the interactive exhibit

CUHK joined hands with the Leisure and Cultural Services Department of the Hong Kong SAR Government to organize an exhibition 'A Tribute to Prof. Charles Kao—Father of Fiber Optics'. From 8 December 2009 to 10 March 2010, members of the public can view the exhibition free-of-charge at the main lobby of the Hong Kong Science Museum. The exhibition introduces Professor Kao's academic life and highlights his significant achievements in the past 40 years. Information panels and material display, interactive exhibits on fiber optics are also on show. Two lectures entitled 'Professor Charles Kao: Pioneer, Scientist, Innovator and Entrepreneur' and 'Optical Fiber Communications: Charm and Challenges', delivered by Prof. Cheung Kwok-wai of the Department of Information Engineering and Prof. Shu Ching-tat Chester of the Department of Electronic Engineering on 12 and 20 December respectively, were warmly received. As at the end of 2009, the exhibition had been visited by over 10,000 people.

Ceramic bowl made by Professor Kao

Professor Kao's portrait was once adopted for the design of commemorative telephone card in Japan

A Campus in Jubilation

December 2009

Alumni Homecoming Special Activities

Organized by the Alumni Affairs Office, the 2009 CUHK Alumni Homecoming held on 13 December featured a series of activities in celebration of Professor Kao's achievements, including a demonstration of optical fiber communication by the Faculty of Engineering, display boards introducing Professor Kao's groundbreaking contributions, and a peep-through board allowing guests to pose for a picture with a caricature of Professor Kao drawn by Mr. Lee Chi-kit, CUHK alumnus. Prof. Cheung Kwok-wai hosted a public lecture on 'The Engineering that Changes the World—Salute to Prof. Charles K. Kao' on the same day.

Optical-fiber communication demonstration

SAND FROM CENTURIES PAST
SEND FUTURE VOICES FAST

A Nobel Lecture

organized by the

Royal Swedish Academy of Sciences

and

The Prize Committee in Physics

delivered by

Mrs. Gwen M.W. Kao

on behalf of

Prof. Charles K. Kao

Nobel Laureate in Physics 2009

8 December 2009

Aula Magna

Stockholm University

1. Introduction

It is sad that my husband, Prof. Charles Kao, is unable to give this lecture to you himself. As the person closest to him, I stand before you to honour him and to speak for him. He is very very proud of his achievements for which the Nobel Foundation honours him. As are we all!

In the 43 years since his seminal paper of 1966 that gave birth to the ubiquitous glass fiber cables of today, the world of telephony has changed vastly. It is due to Prof. Kao's persistence in the face of skepticism that this revolution has occurred.

In the 1970s the pre-production stage moved to ITT Corp Roanoke VA, USA. Whilst Charles worked there, he received two letters. One contained a threatening message accusing him of releasing an evil genie from its bottle; the other, from a farmer in China, asked for a means to allow him to pass a message to his distant wife to bring his lunch. Both letter writers saw a future that has since become past history.

In the 60s, our children were small. Charles often came home later than normal — dinner was waiting as were the children. I got very annoyed when this happened day after day. His words, maybe not exactly remembered, were —

'Please don't be so mad. It is very exciting what we are doing; it will shake the world one day!'

I was sarcastic, 'Really, so you will get the Nobel Prize, will you!'

He was right — it has revolutionized telecommunications.

2. The early days

In 1960, Charles joined Standard Telecommunications Laboratories Ltd. (STL), a subsidiary of ITT Corp in the UK, after having worked as a graduate engineer at Standard Telephones and Cables in Woolwich for some time. Much of the work at STL was devoted to improving the capabilities of the existing communication infrastructure with a focus on the use of millimetre wave transmission systems.

Millimetre waves at 35 to 70 GHz could have a much higher transmission capacity. But the waters were uncharted and the challenges enormous, since radio waves at such frequencies could not be beamed over long distances due to beam divergence and atmospheric absorption. The waves had to be guided by a waveguide. And in the 1950s, R&D work on low loss circular waveguides — HE-11 mode — was started. A trial system was deployed in the 1960s. Huge sums were invested, and more were planned, to move this system into the pre-production stage. Public expectation for new telecommunication services such as the video phone had heightened.

Charles joined the long-haul waveguide group led by Dr. Karbowiak at STL. He was excited to see an actual circular waveguide. He was assigned to look for new transmission methods for microwave and optical transmission. He used both ray optics and wave theory to gain a better understanding of waveguide problems — then a novel idea. Later, his boss encouraged him to pursue a doctorate while working at STL. So Charles registered at University College London and completed the dissertation 'Quasi-Optical Waveguides' in two years.

The invention of the laser in 1959 gave the telecom community a great dose of optimism that optical communication could be just around the corner. The coherent light was to be the new information carrier with capacity a hundred thousand times higher than point-to-point microwaves — based on the simple comparison of frequencies: 300 terahertz for light versus 3 gigahertz for microwaves.

The race between circular microwave waveguides and optical communication was on, with the odds heavily in favor of the former. In 1960, optical lasers were in their infancy, demonstrated at only a few research laboratories, and performing much below the needed specs. Optical systems seemed a non-starter.

But Charles still thought the laser had potential. He said to himself: 'How can we dismiss the laser so readily?' 'Optical communication is too good to be left on the theoretical shelf.'

He asked himself the obvious questions:

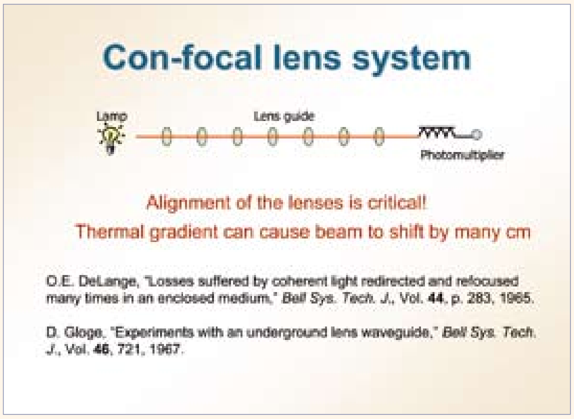
1. Is the ruby laser a suitable source for optical communication?
2. What material has sufficiently high transparency at such wavelengths?

At that time only two groups in the world were starting to look at the transmission aspect of optical communication, while several other groups were working on solid state and semiconductor lasers. Lasers emit coherent radiation at optical frequencies, but using such radiation for communication appeared to be very difficult, if not impossible. For optical communication to fulfill its promises, many serious problems remained to be solved.

3. The key discovery

In 1963 Charles was already involved in free space propagation experiments: The rapid progress of semiconductor and laser technology had opened up a broader scope to explore optical communication realistically. With a helium-neon laser beam directed to a spot some distance away, the STL team quickly discovered that distant laser light flickered. The beam danced around several beam diametres because of atmospheric fluctuations.

The team also tried to repeat experiments done by other research laboratories around the world. For example, they set up con-focal lens experiments similar to those at Bell Labs: a series of convex lenses were lined up at intervals equal to the focal length. But even at the



dead of night when the air was still and even with refocusing every 100 metres, the beam refused to stay within the lens aperture.

Bell Labs experiments using gas lenses were abandoned due to the difficulty of providing satisfactory insulation while maintaining the profiles of the gas lenses. These experiments were struggles in desperation, to control light travelling over long distances.

At STL the thinking shifted towards dielectric waveguides. Dielectric means a non-conductor of electricity; a dielectric waveguide is a waveguide consisting of a dielectric cylinder surrounded by air. Dr. Karbowiak suggested Charles and three others to work on his idea of a thin film waveguide.

But thin film waveguides failed: the confinement was not strong enough and light would escape as it negotiates a bend.

When Dr. Karbowiak decided to emigrate to Australia, Charles took over as the project leader and he then recommended that the team should investigate the loss mechanism of dielectric materials for optical fibers.

A small group worked on methods for measuring material loss of low-loss transparent materials. George Hockham joined him to work on the characteristics of dielectric waveguides. With his interest in waveguide theory, he focused on the tolerance requirements for an optical fiber waveguide; in particular, the dimensional tolerance and joint losses. They proceeded to systematically study the physical and waveguide requirements on glass fibers.

In addition, Charles was also pushing his colleagues in the laser group to work towards a semiconductor laser in the near infrared, with emission characteristics matching the diametre of a single-mode fiber. Single mode fiber is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier. The laser had to be made durable, and to work at room temperatures without liquid nitrogen cooling. So there were many obstacles. But in the early 1960s, esoteric research was tolerated so long as it was not too costly.

Over the next two years, the team worked towards the goals. They were all novices in the physics and chemistry of materials and in tackling new electromagnetic wave problems. But they made very credible progress in considered steps. They searched the literature, talked to experts, and collected material samples from various glass and polymer companies. They also worked on the theories, and developed measurement techniques to carry out a host of experiments. They developed an instrument to measure the spectral loss of very low-loss material, as well as one for scaled simulation experiments to measure fiber loss due to mechanical imperfections.

Charles zeroed in on glass as a possible transparent material. Glass is made from silica — sand from centuries past that is plentiful and cheap.

The optical loss of transparent material is due to three mechanisms: (a) intrinsic absorption, (b) extrinsic absorption, and (c) Rayleigh scattering. The intrinsic loss is caused by the infrared absorption of the material structure itself, which determines the wavelength of the transparency regions. The extrinsic loss is due to impurity ions left in the material and the Rayleigh loss is due to the scattering of photons by the structural non-uniformity of the material. For most practical applications such as windows, the transparency of glass was entirely adequate, and no one had studied absorption down to such levels. After talking with many people, Charles eventually formed the following conclusions.

1. Impurities, particularly transition elements such as iron, copper, and manganese, have to be reduced to parts per million or even parts per billion. However, can impurity concentrations be reduced to such low levels?

2. High temperature glasses are frozen rapidly and therefore are more homogeneous, leading to a lower scattering loss.

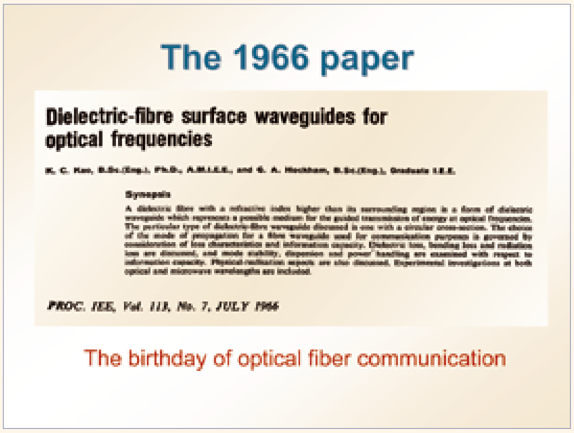
The ongoing microwave simulation experiments were also completed. The characteristics of the dielectric waveguide were fully defined in terms of its modes, its dimensional tolerance both for end-to-end mismatch and for its diametre fluctuation along the fiber lengths. Both the theory and the simulated experiments supported the approach.

They wrote the paper entitled, 'Dielectric-Fiber Surface Waveguides for Optical Frequencies' and submitted it to the *Proceedings of Institute of Electrical Engineers*. After the usual review and revision, it appeared in July 1966 — the date now regarded as the birthday of optical fiber communication.

4. The paper

The paper started with a brief discussion of the mode properties in a fiber of circular cross section.

The paper then quickly zeroed in on the material aspects, which were recognized to be the major stumbling block. At the time, the most transparent glass had a loss of 200 dB/km, which would limit transmission to about a few metres — this is very obvious to anyone who has ever peered through a thick piece of glass. Nothing can be seen.



But the paper pointed out that the intrinsic loss due to scattering could be as low as 1 dB/km, which would have allowed propagation over practical distances. The culprit is the impurities: mainly ferrous and ferric ions at these wavelengths. Quoting from the paper: 'It is foreseeable that glasses with a bulk loss of about 20 dB/km at around 0.6 micron will be obtained, as the iron-impurity concentration may be reduced to 1 part per million'. In layman terms, if one has a sufficiently 'clean' type of glass, one should be able to see through a slab as thick as several hundred metres. That key insight opened up the field of optical communications.

The paper considered many other issues:

- The loss can be reduced if the mode is chosen so that most of the energy is actually outside the fiber.
- The fiber should be surrounded by a cladding of lower index (which became the standard technology).
- The loss of energy due to bends in the fiber is negligible for bends larger than 1 mm.
- The losses due to non-uniform cross sections were estimated.
- The properties of a single-mode fiber (now a key technology especially for long distance and high data rate transmission) were analyzed. It was explained how dispersion limits bandwidth; an example was worked out for a 10 km route — a very bold scenario in 1966.

It may be appropriate to quote from the Conclusion of this paper:

> The realization of a successful fiber waveguide depends, at present, on the availability of suitable low-loss dielectric material. The crucial material problem appears to be one which is difficult but not impossible to solve. Certainly, the required loss figure of around 20 dB/km is much higher than the lower limit of loss figure imposed by fundamental mechanisms.

Basically all of the predictions pointed accurately to the paths of developments, and we now have 1/100 of the loss and 10,000 times the bandwidth then forecast — the revolutionary proposal in the 1966 paper was in hindsight too conservative.

5. Convincing the world

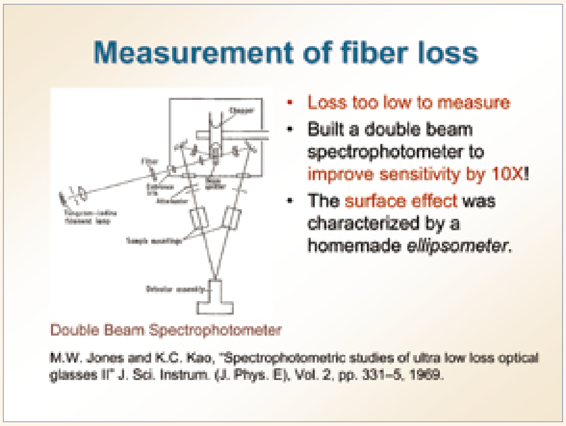
The substance of the paper was presented by Dr. Kao at an IEE meeting in February 1966. Most of the world did not take notice — except for the British Post Office (BPO) and the UK Ministry of Defense, who immediately launched major research programs. By the end of 1966, three groups in the UK were studying the various issues involved: Kao himself at STL; Roberts at BPO; Gambling at Southampton in collaboration with Williams at the Ministry of Defense Laboratory.

In the next few years, Dr. Kao travelled the globe to push his idea: to Japan, where enduring friendships were made dating from those early days; to research labs in Germany, in the Netherlands and elsewhere to spread his news. He said that until more and more jumped on the bandwagon, the use of glass fibers would not take off. He had tremendous conviction in the face of widespread skepticism. The global telephony industry is huge, too large to be changed by a single person or even a single country, but he was persistent and his enthusiasm was contagious, and slowly he converted others to be believers.

The experts at first proclaimed that the materials were the most severe of the intrinsic insurmountable problems. Gambling wrote that British Telecom had been 'somewhat scathing' about the proposal earlier, and Bell Labs, who could easily have led the field, simply failed to take notice until the proven technology was pointed out to them. Dr. Kao visited many glass manufacturers to persuade them to produce the clear glass required. He got a response from Corning, where Maurer led the first group that later produced the glass rods and developed the techniques to make the glass fibers to the required specifications.

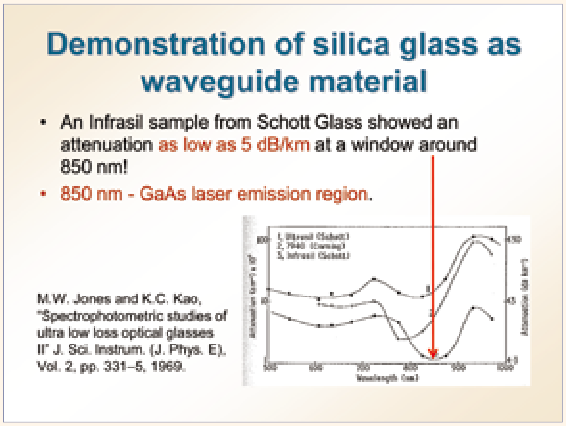
Meanwhile, Dr. Kao continued to pour energy into proving the feasibility of glass fibers as the medium for long-haul optical transmission. They faced a number of formidable challenges. The first was the measurement techniques for low-loss samples that were obtainable only in lengths of around 20 cm. The problem of assuring surface perfection was also formidable. Another problem is end surface reflection loss, caused by the polishing process. They faced a measurement impasse that demanded the detection of a loss difference between two samples of less than 0.1%, when the total loss of the entire 20 cm sample is only 0.1%. An inexact measurement would be meaningless.

In 1968 and 1969, Dr. Kao and his colleagues Davies, Jones and Wright at STL published a series of papers on the attenuation measurements of glass that addressed the above problems. At that time, the measuring instruments called spectrophotometres had a rather limited sensitivity — in the range of 43 dB/km. The measurement was very difficult: even a minute contamination could have caused a loss comparable to the attenuation itself, while surface effects could easily be 10 times worse. Dr. Kao and the team assembled a homemade single-beam spectrophotometre that achieved a sensitivity of 21.7 dB/km. Later improvements with a double-beam



spectrophotometer yielded a sensitivity down to 4.3 dB/km.

The reflection effect was measured with a homemade ellipsometer. To make it, they used fused quartz samples made by plasma deposition, in which the high temperature evaporated the impurity ions. With the sensitive instrument, the attenuation of a number of glass samples was measured and, eureka, the Infrasil sample from Schott Glass showed an attenuation as low as 5 dB/km at a window around 0.85 micron — at last proving that the removal of impurity would lower the absorption loss to useful levels.



This was really exciting because the low-loss region is right at the gallium-arsenide laser emission band. The measurements clearly pointed the way to optical communication — compact gallium-arsenide semiconductor lasers as the source, low-cost cladded glass fibers as the transmission medium, and silicon or germanium semiconductors for detection. The dream no longer seemed remote. These measurements apparently turned the sentiments of the research community around. The race to develop the first low-loss glass fiber waveguide was on.

In 1967, at Corning, Maurer's chemist colleague Schultz helped to purify the glass. In 1968, his colleagues Keck and Zimar helped to draw the fibers. By 1970, Corning had produced a fiber waveguide with a loss of 17 dB/km at 0.633 micron using a titanium-diffused core with silica cladding, using the Outside Vapor Deposition (OVD) method. Two years later, they reduced the loss to 4 dB/km for a multimode fiber by replacing the titanium-doped core with a germanium-doped core.

Bell Labs finally got on the bandwagon in 1969 and created a program in optical fiber research after having been skeptical for years. Their work on hollow light pipes was finally stopped in 1972. Their millimetre wave research programme was wound down and eventually abandoned in 1975.

It was during this time of constant flying out to other places that this cartoon joke hit home: ‘Children, the man you see at the breakfast table today is your father!’

We saw him for a few days and off he went again. Sometimes he flew off for the day for meetings at ITT Corp headquarters in New York. I would forget he had not left to go to the office and would phone his secretary to remind Charles to pick up milk or something on his way home. His secretary was very amused:

‘Mrs. Kao, don’t you know your husband is in New York today!’

6. Impact on the world

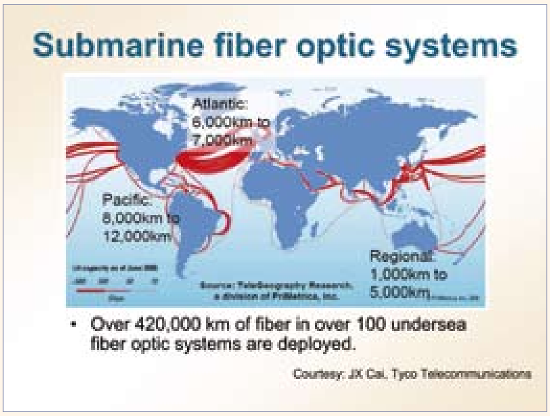
Since the deployment of the first-generation, 45-megabit-per-second fiber-optic communication system in 1976, the transmission capacity in a single fiber has rapidly increased a million fold to tens of terabits per second. Data can be carried over millions of km of fibers without going through repeaters, thanks to the invention of the optical fiber amplifier and wavelength division multiplexing. So that is how the industry grew and grew.

The world has been totally transformed because of optical fiber communication. The telephone system has been overhauled and international long distance calls have become easily affordable.

Brand new mega-industries in fiber optics including cable manufacturing and equipment, optical devices, network system and equipment have been created.

Hundreds of millions of kilometres of glass fiber cables have been laid, in the ground and in the ocean, creating an intricate web of connectivity that is the foundation of the world-wide web.

The Internet is now more pervasive than the telephone used to be. We browse, we skype, we blog, we go onto YouTube, we shop, we socialize on-line. The information revolution that started in the 1990s could not have happened without optical fibers.



Over the last few years fibers are being laid all the way to our homes. All-optical networks that are environmentally green are contemplated. The revolution in optical fiber communication has not ended — it might still just be at the beginning.

7. Conclusion

The world-wide communication network based on optical fibers has truly shrunk the world and brought human beings closer together. I hardly need to cite technical figures to drive this point home. The news of the Nobel Prize reached us in the middle of the night at 3 am in California, through a telephone call from Stockholm (then in their morning) no doubt carried on optical fibers; congratulations came literally minutes later from friends in Asia (for whom it was evening), again through messages carried on optical fibers. Too much information is not always a good thing: we had to take the phone off the hook that night in order to get some sleep!

Optical communication is by now not just a technical advance, but has also caused major changes in society. The next generation will learn and grow up differently; people will relate to one another in different ways. Manufacturing of all the bits and pieces of a single product can now take place over a dozen locations around the world, providing huge opportunities for people especially in developing countries. The wide accessibility of information has obviously led to more equality and wider participation in public affairs.

Many words, indeed many books have been written about the information society, and I do not wish to add to them here — except to say that it is beyond the dreams of the first serious concept of optical communication in 1966, when even 1 GHz was only a hope. How long will fiber last? I'd like to let Charles speak for himself:

In conclusion, Charles and I want to thank the Professors at The Chinese University of Hong Kong, namely: Prof. Young, Prof. Wong, Prof. Cheung and Prof. Chen for their support in compiling this lecture for us. Charles would like to thank ITT Corp where he developed his career for 30 years and all those who climbed on to the bandwagon with him in the early days, as without the legions of believers the industry would not have evolved as it did.

Charles Kao planted the seed; Bob Maurer watered it and John MacChesney grew its roots.

Thank you.

This lecture was prepared with the help of Mrs. Gwen Kao, Lian-kuan Chen, Kwok-wai Cheung, Melody Lee, Wing-shing Wong and Kenneth Young. The poetic title of the lecture was created by Mrs. Gwen Kao. A formal version of the lecture will appear in the Nobel yearbook *Les Prix Nobel* to be published later.

A Short Biography of Prof. Charles K. Kao

1933 Born in Shanghai on 4 November

1949 Moved to Hong Kong, received secondary education at St. Joseph's College

1953 Enrolled in matriculation course of Woolwich Polytechnic, University of London

1957
- Awarded the degree of BSc in Engineering by the University of London
- Joined the International Telephone and Telegraph Corporation and was then transferred to the Corporation's Standard Telecommunications Laboratories in 1960

1965 Awarded the degree of PhD by the University College London

1966 Published a paper which proposed using glass fibers as a conductor for optic communication, ushering in the era of optic fiber communication

1970 Joined CUHK as reader and chair of the then new Department of Electronics, later appointed as the first Professor of Electronics

1985 Conferred the degree of Doctor of Science, *honoris causa*, by CUHK; awarded the Alexander Graham Bell Medal by The Institute of Electrical and Electronics Engineers and received the Marconi International Fellowship

1987 Became Vice-Chancellor of CUHK

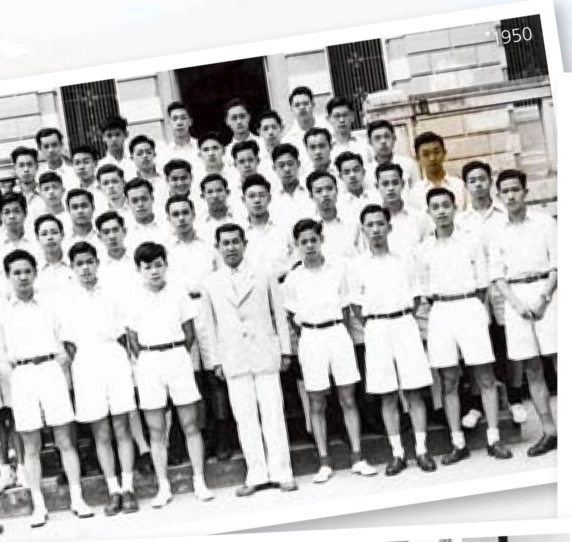
1992 Appointed Centenary Fellow of Thames Polytechnic (now renamed Greenwich University)

1996
- Retired in July from vice-chancellorship and since then became Honorary Professor of Engineering
- A minor planet (3463) was named after him as 'Kaokuen' by the Purple Mountain Observatory of the Chinese Academy of Sciences
- Received the Japan Prize of the Science and Technology Foundation of Japan

1999 Awarded the Charles Stark Draper Prize by the National Academy of Engineering, USA

2005 Chinese autobiography published

2009 Awarded the Nobel Prize in Physics by the Royal Swedish Academy of Sciences



*1950

*1952

*1970s

1987

1996

2007

2009

Homecoming

Professor and Mrs. Kao have kindly accepted CUHK's invitation to grace the campus with their presence in the spring of 2010. They will meet old friends and officiate at a series of events:

'**The Lore of a Laureate: A Tribute to Charles Kao, Former CUHK Vice-Chancellor and Nobel Laureate**' — The opening ceremony of the exhibition will be held on 5 February at the Reading Room, 6/F, Ho Sin-Hang Engineering Building on campus. The exhibition will move to the Exhibition Hall, University Library on the following day and will run until 20 March.

Establishment of the Charles K. Kao Scholarship Endowment Fund — To provide awards for outstanding full-time undergraduate students majoring in physics and engineering, based on academic achievements and potential for scientific research and innovation.

'Walk with Professor Kao' CUHK Walkathon — Held in support of the Charles K. Kao Scholarship Endowment Fund, the event will kick off at Lingnam Stadium, Chung Chi College on the morning of 14 March.

A bronze statue of Professor Kao is being planned for. Details of the statue unveiling ceremony and other events above can be found at *www.cuhk.edu.hk/cpr/charleskao/index-e.html*.

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