PHOTONICS Research

Photonics Research Interview with Professor Connie Chang-Hasnain

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Professor Connie Chang-Hasnain discusses her career in semiconductor optoelectronics with her former student, Prof. Hao Sun. © 2024 Chinese Laser Press

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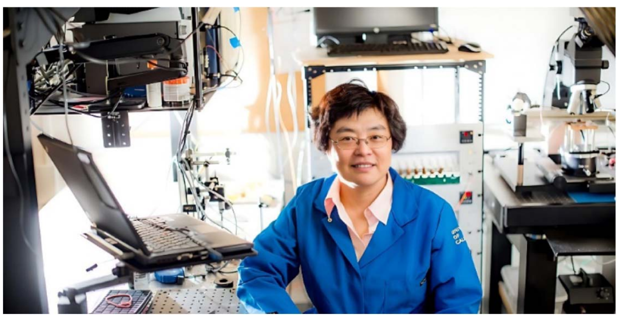
The third interview for a *Photonics Research* webinar series took place on 15 November 2023. *Photonics Research* Assistant Editor, Prof. Hao Sun, interviewed her PhD advisor, Prof. Connie Chang-Hasnain, University of California, Berkeley, United States and Berxel Photonics, China. Prof. Chang-Hasnain is a world-renowned scientist in the field of semiconductor optoelectronics. Her accomplishments have been documented by numerous awards and honors. In addition to being a faculty member for over 25 years at the University of California, Berkeley, giving guidance and advice to students and young researchers, she is also a community leader, serving as Editor-in-Chief for the *Journal of Lightwave Technology*, from 2007 to 2012, and the former President of Optica, and is also an entrepreneur, starting a couple of companies.

We are pleased to provide the interview transcript below for others to read and learn from Prof. Chang-Hasnain's remarkable career and insights.

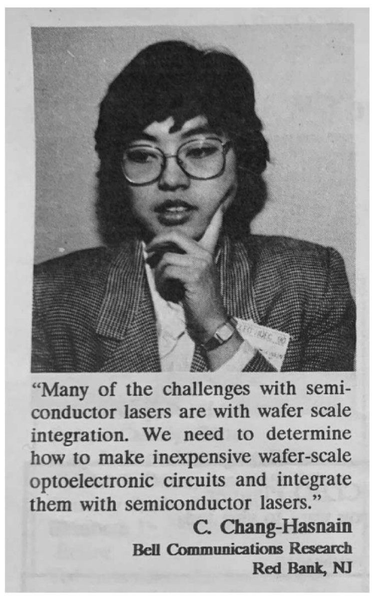


Connie Chang-Hasnain in her lab at UC Berkeley.

Hao Sun: You have made pioneering contributions to the physics, design, and applications of vertical cavity surface-emitting lasers (VCSELs) and you have been in this area for years. How did you get involved in this field?

Connie Chang-Hasnain: It was a really opportunistic time. I was very lucky. In 1989 I was a young researcher at Bellcore working on semiconductor laser arrays.

In fact, one of the hottest topics at the time was about designing a laser array that can emit distinctly different wavelengths for wavelength-division multiplexing or WDM transmission. At that time, Prof. Kenichi Iga had just demonstrated the first room-temperature VCSEL in 1988 and Jack Jewell and Jim Harbison reported their early work on as-grown DBR (distributed Bragg reflector) VCSELs in 1989. I looked at the VCSEL topology and thought it was just perfect for the purpose of WDM array. So, I jumped at the opportunity and made the first 2D VCSEL array emitting 140 distinctly different wavelengths. I further demonstrated the first planar VCSEL array modulated at Gbps for multimode fiber transmission. That was how I entered the field.



Connie Chang-Hasnain at Bellcore as a young researcher attending CLEO 1988.

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Connie Chang-Hasnain with Kenichi Iga at Berkeley in 2005.

Sun: Can you expand the significance of your work on VCSELs and how have they reshaped the landscape of optoelectronics, or what is the most important impact of VCSELs in our daily life?

Chang-Hasnain: First of all, I should say that most of the work I will be discussing today are results of collaborations with my colleagues and students at Bellcore, Stanford, and Berkeley. I also collaborated with many universities, USC, UIUC, Tsinghua University, and Tokyo Institute of Technology. I must apologize for not being able to name them all due to limited time, but I thank them very much for their contributions to the work.

As I mentioned, I was looking for WDM sources for optical communications. And in 1990, we reported the first gigabit modulation of VCSEL arrays transmitting through multimode fiber arrays. We made transverse mode analysis and theoretical studies of the properties of VCSELs. We made 2D arrays, both individually as well as matrix addressable arrays. All of these, I believe, laid a solid foundation for multimode fiber transceivers today. Today, multimode VCSELs are used as multimode fiber transceivers in data centers from the initial 1 Gbps, to today's 50 Gbps/lane and 100 Gbps/lane applications. VCSELs in the past 20 years have been the workforce for data center communications and will remain to be so for a long time to come.

In 1998, we published the first large laser array, 1000-emitter VCSEL array, emitting 940 nm wavelength for 3D distance measurement and LIDAR application. We chose this wavelength because there's a strong optical absorption, so one can avoid stray light interference. That, to the best of our knowledge, was the first 940 nm VCSEL for 3D sensing. Today all 3D sensors used in smartphones are based on 940 nm wavelength VCSEL arrays.

Sun: Yes, the LIDAR and facial recognition based on VCSEL arrays have changed our lives. I know that you also created tunable VCSELs that allow for wavelength selection and facilitate applications in optical communications and spectroscopy analysis. Can you elaborate on how those advancements influence the field of optoelectronics in terms of market applications and industry innovations?

Chang-Hasnain: Wavelength tunable lasers have always been of great interest for a variety of system applications. It is common to design an electronic resonator whose oscillating frequency can be tuned. In fact, such a tunable resonator is a fundamental building block for electronic circuits. However, for a laser, which is also a resonator, it's really difficult to sweep or tune continuously its oscillating frequency (i.e., its wavelength).

We looked at this problem and we wanted to solve it. And it was really quite lucky. I had a colleague, whose office was next to mine, working on MEMS (micro-electromechanical systems). His work inspired my group. We decided to make a VCSEL having its top DBR mirror on a MEMS structure, and by moving the DBR-MEMS, you can change the cavity length of the laser, and thereby change its wavelength. It turns out that because VCSEL has an ultrashort cavity, it emits a single longitudinal mode. As a result, by moving the MEMS mirror, the VCSEL's wavelength can be continuously tuned over a wide range. In addition, the MEMS is so tiny, you can move it very, very fast—100 kHz, or even several megahertz. Thus, we demonstrated a laser whose wavelength can be continuously swept. This is a unique feature that cannot be obtained by any other laser structure. Now MEMS-VCSELs are being used for swept source OCT (optical coherence tomography) in the applications of ophthalmology, cardiology, gastroenterology, and so on. With the fast-swept speed, one can observe micron-depth features over a wider field of view and actually see features that could not be observed before.

Sun: Just now you have already mentioned DBRs. When I was at Berkeley, you made impressive contributions to the high contrast grating to replace bulky DBRs and apply them to VCSELs. What is the motivation to investigate this? Would you share the story behind this work?

Chang-Hasnain: A VCSEL has a vertical cavity, and the gain length is just the quantum well thickness. Comparing to a regular edge emitting laser, VCSEL's gain length is 10,000 times shorter and, as a result, a VCSEL requires two very high reflectivity mirrors. The standard mirror structure is an as-grown semiconductor DBR composed of many pairs of quarter-lambda thick, alternating refractive index layers. The reflection from each interface adds coherently resulting in a high reflectivity mirror. Because of the material choice, the refractive index difference (Δn) is quite small, and as a result we need to use many tens of DBR pairs. The resulting VCSEL epitaxy may be more than 10 μm thick with material grown over ~10 h, which presents significant difficulty in maintaining growth accuracy and precision. Hence, achieving high reflectivity DBRs has been one of the most difficult parts of making a VCSEL epitaxy.

So, we've been thinking—the high reflectivity comes from periodicity, which is in the direction of beam propagation, and as a result, a high reflectivity DBR is very thick. What if the periodicity is in the direction orthogonal to beam propagation? Would it be possible to obtain a high reflectivity mirror? And so, we started our investigation. We found that, indeed, it was possible! It's simply the Faraday cage, which has been used for microwave and electromagnetic waves. The Faraday cage is just a single thin layer of periodic metal mesh and can completely reflect the microwaves. This gave us the inspiration!

However, at the optical wavelengths, metal is lossy and not desirable as a VCSEL mirror. So, we thought about using a dielectric or semiconductor mesh to mimic the effect of metal mesh. This led to using a high refractive-index contrast mesh to mimic a Faraday cage. And it turns out one can make a mirror with both 1D or 2D high index contrast structures. We proved this by simulation in 2004 and later with theoretical analysis and by experiments. In fact, subsequently, we found the high contrast gratings (HCGs) or 2D metastructures (HCMs) can do much more than the Faraday cage.

A high contrast grating or metastructure can provide high reflection. But by changing the thickness of the HCG/HCM, one can get an anti-reflection coating or a resonator with high quality factor more than 1 million; and by varying the other dimensions, i.e., width and period, one can modulate its reflection or transmission phase resulting in interesting flat optics such as a lens or beam shaper.… We reported a high numerical aperture lens, a beam bender, a surface-normal modulator, a biosensor, and a nonlinear optics four-wave mixer. This has just been a tremendous amount of fun!

It is worthwhile to point out that we started with analytical solution of dielectric waveguides and found great physical insights for top–down designs, which can be used to complement the more recent inverse design approach.

Of course, we made HCG to replace a DBR on a VCSEL. In addition to being ultrathin, the HCG allows to control VCSEL transverse mode and get a fixed polarization. And using this property, Berxel Photonics, the company I founded four years ago, has launched HCG-VCSEL as a product for 3D sensors. In 3D sensing, the biggest problem is to avoid multipath reflection, particularly from highly reflecting surfaces, e.g., glass door, glass panel mirrors, metal walls, or water surface. HCG VCSEL array with fixed polarization in conjunction with an HCG polarizer at the receiver forms the best solution to eliminate multipath interferences [1].

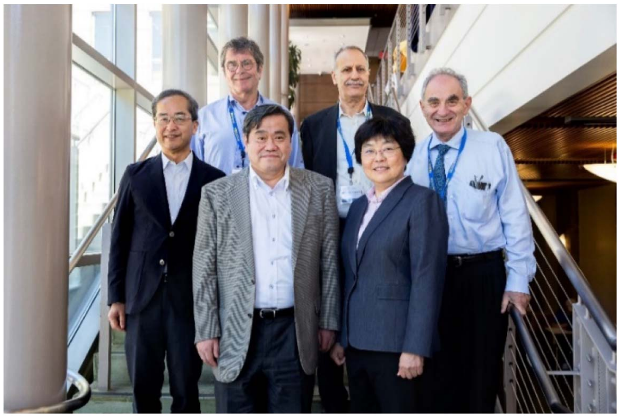
Connie Chang-Hasnain in the laboratory at Berxel Photonics.

Sun: It's amazing that such a thin layer of high contrast grating can replace so many pairs of DBRs. And the HCG can be employed in a lot of nonoptoelectronic structures and play important key roles.

The audience is also very curious about VCSELs. We have two questions from the audience regarding VCSELs. What are the recent breakthroughs in VCSELs? This question is from a student at Soochow University. Another question is from a researcher at Lumentum Operations. He asked, what is a VCSEL bandwidth upper limit with higher speed module deployment in a DCN network (dynamic circuit network).

Chang-Hasnain: I think the most exciting work in the recent few years includes a paper we reported in collaboration with Prof. Larry Coldren at UC Santa Barbara on the widest tuning range of VCSELs using anti-resonant coupled cavity. This is a very counterintuitive design. We were able to get a very wide tuning range, ~80 nm at 1050 nm center-wavelength, close to 8%–10% of tuning range to wavelength ratio.

Another very exciting work is Prof. Koyama's recent work on bandwidth enhancement laser using transverse coupled cavity and metal aperture coupled cavity. In both designs, Prof. Koyama was able to get 100 Gbps modulation speed. Prof. Bimberg also used multiple small oxide aperture VCSELs, allowing them to couple and get very, very high-speed operation. I think, in general, the theme of coupling of cavities in VCSEL, whether it's transverse or vertical, is a rich and very exciting area.



Left to right: Yasuhiko Arakawa, Dieter Bimberg, Fumio Koyama, Abderrahim Ramdane, Connie Chang-Hasnain, and Eli Yablonovitch, Co-Chairs of 2018 International Nano-Optoelectronics Workshop (iNOW) at Berkeley.

As to the second question, edge-emitting lasers have just demonstrated 200 Gbps modulation speed. I am very optimistic about VCSELs reaching 200 Gbps. Currently, Berxel Photonics has 100 Gbps/channel VCSELs, among one of the first companies to deliver products with this modulation speed at 850 nm range. I think the entire community is excited about VCSELs for high-speed modulation for datacom applications.

Sun: Besides your outstanding scientific achievement, you are also famous for your great success in technology transfer from academia to industry. You mentioned commercializing the HCG-based VCSEL into a real product and you founded the company Berxel Photonics four years ago. Developing such groundbreaking technologies and converting them into products that can be used in real-world applications is undoubtedly challenging. Could you share with us some of the main obstacles that you encountered during the development?

Chang-Hasnain: I have to say, making a product is a humbling experience. I have enormous respect and appreciation towards the entire process of making a product. To all the engineers from Broadcom, Coherent, Sony, Lumentum, Ulm Photonics, Trumpf Photonics etc., my hat's off to you for making VCSELs a reality.

I feel the most important thing about making a product is meticulous attention to details. Details really matter. And a recipe must be repeatable, reproducible, and reliable before it can be turned into a product. There are many steps that one must take to ensure this happens. Also, it is a team effort. One has to have a team of people who believe in a big vision, but care about every single little step. I'm still learning. I want to acknowledge our team at Berxel Photonics, whose hard work made it possible for us to have volume production for 50 Gbps VCSEL as well as 3D sensors, and to be ready for production for 100 Gbps VCSEL for data center communications.

Sun: Yes, for the real products, the process is totally different from research. In research, we always try to find the "hero data." But for real products we need reproducibility, reliability, and so on, like you said. You mentioned the team. This links to my next question. What strategy have you employed to foster innovation and success in your team, both in your company and research?

Chang-Hasnain: I think sharing is the key word; sharing approaches, successful results and unsuccessful ones, new and half-cooked ideas, and problems, etc. Only when one is capable to share unsuccessful experiments, one can succeed. Many brains are better than one. Through the process of sharing problems and bouncing ideas back and forth, one can improve. I try to build an environment where my group feels comfortable sharing. I believe that's the key ingredient for innovation. Of course, innovation also takes solitary thinking and reading and diligence, which all of us do. But I think sharing is how we can make our world better.

Sun: I am especially interested in the next question. I learned so much under your mentorship during my three years at Berkeley. How do you stay motivated and maintain your enthusiasm for research and industry, especially during the times when the result may not be as expected? Any other specific qualities or skills that are crucial for success for a young scientist, in particular?

Chang-Hasnain: I think you have the quality exactly. You spent three years in that basement without a window! In the laboratory, very often, late nights working on the tiny little nanowires that you could not find or see with a microscope, but needed to focus light down to one micron roughly to see the results with very tiny luminescence. What a tough job you had! I'm sorry for giving you such a tough problem! But you did so fantastically which resulted in many important papers and a Best PhD Thesis award. This is a great example!

The example is believing in yourself, right? And being optimistic even if one gets really poor results, and to have the courage to continue on. The important thing is to always analyze the problem and fix it. When I get really upset, I would watch a sad movie, and then I cry a bit to relax and release all the anxiety. And of course, I would talk to family members, friends, and colleagues. But, above all, don't give up and don't give in! Continue to believe in oneself.

Connie Chang-Hasnain with her husband Ghulam Hasnain, as Chang-Hasnain is being inducted into the National Academy of Engineering in 2018.

Sun: Apart from your scientific pursuits, what hobbies or activities do you enjoy in your free time? What advice would you give about maintaining a positive work–life balance?

Chang-Hasnain: I have to say I really don't have a hobby, *per se*. A hobby is something that is outside of work that you pursue and practice. I truly don't have that. I spend all of my time either at home or work, doing my duties, but I truly enjoy them. Work has been tremendously fun, especially interacting with students and colleagues. But if I do have time, I watch some movies. And I also like to sing. I sing poorly, but I asked my students to sing with me. I also organize conferences and workshops, and particularly, plan parties during conferences and workshops, and I really enjoy that. I make a lot of friends that way. And then finally, I read a bit; and I love to read history books. I'm hoping to learn some lessons from history.

Sun: Another question from the audience is from a young researcher from the University of Science and Technology of China that just finished his doctoral thesis. His research direction is theoretical research of leaky modes of the fiber grating. He thinks it's difficult to find real applications, and he feels very confused, so, he's asking for advice from you.

Connie Chang-Hasnain interacting with students.

Chang-Hasnain: Leaky modes in fibers are very important for sensor applications. I would suggest asking his advisors and also colleagues. It is very useful to go to conferences and listen to talks, not only in his specific area but also other different ones. There are many commonalities that one can borrow. Also, a PhD degree is a basic license that means you can solve problems. One may now use the same methodologies to explore new areas. So be brave to explore! Don't be afraid to get into new areas.

Sun: You are taking on a lot of roles, not only about education, industry, and different community service activities. And you are the second Chinese scientist elected as Optica President after Prof. Tingye Li. How did you leverage this position to promote advancements in the field of optoelectronics? Also, as someone who has witnessed the growth and development of both Optica and Chinese Laser Press (CLP), how do you think these kinds of organizations will play important roles in shaping the field of optics and photonics?

Chang-Hasnain: First, I'm extremely honored to be a follower of Dr. Tingye Li. I followed him since 2000 when he started to organize a large number of conferences internationally. I feel like an adopted disciple of Tingye. And for that, I'm really grateful. I learned a lot from Tingye. He was really selfless and dedicated to promoting young scholars and students. Very often you would see him at conferences being surrounded by students, and he loved to give advice and guidance. He was a great role model to follow.

During my presidency in 2021, Optica rolled out its core values: inclusivity, impact, innovation, and integrity. I truly believe in them, and in particular, inclusivity. Inclusivity is about including everyone despite differences in nationality, race, gender, and ethnic origin, etc. We want to reach out because science has no borders.

I want to serve as a vehicle and a bridge to connect international communities. I'm continuing to organize and serve on international workshops. I am co-chairing iNOW, the International Nano-Optoelectronics Workshop, which will be held in China this year. In addition, I believe in international cooperation, particularly professional societies. I participated in the recording for a special program called "Five Minutes in Optics" of the CLP WeChat Platform, to introduce VCSEL and its application to the audience. I also gave the opening remarks on behalf of Optica at ACP 2020 (Asia Communications and Photonics Conference). I am pleased that *Photonics Research* and *Chinese Optics Letters*, both of which are co-published by CLP and Optica Publishing Group, are doing extremely well as publications.

Connie Chang-Hasnain at iNOW 2007 with Eli Yablonovitch, Ivan Kaminow, Ming Wu, Haolin Chen, and the UC Berkeley team.

Connie Chang-Hasnain's Recording for "Five Minutes in Optics."

Sun: Thank you for speaking with me today. I have learned so much about your remarkable and invaluable experiences and I'm sure that many people in the audience today will benefit from them. I also want to thank you for having me in your group. Your mentorship provided me with valuable insight and constructive feedback, which greatly contributed to my skills. I sincerely appreciate your dedication, patience, and willingness to invest your time and effort in helping me become a better professional. I think I will always cherish the knowledge and lessons you imparted to me. Thank you, Connie.

Chang-Hasnain: I am grateful for the opportunity to speak with you. I enjoyed tremendously working with you in the past and appreciate the conversation today.

Connie Chang-Hasnain, Lianshan Yan with CLP staff at ACP 2020.

NOTE

1. Berxel iHawk P100 Polarization Structured Light Camera was selected a 2024 R&D 100 Winner, https://www.rdworldonline.com/rd-100-winners-for-2024-are-announced/.