PHOTONICS Research

Photonics Research Interview with Professor John Bowers

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Professor John Bowers discusses his career in integrated photonics with his former student, Prof. Lin Chang.

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The second interview for a *Photonics Research* webinar series took place on 28 November 2022. Professor Lin Chang interviewed his former PhD supervisor, Prof. John Bowers, University of California, Santa Barbara, United States. He is a world-renowned leader and entrepreneur in the field of integrated photonics for optics communications. He has founded many start-ups, including Terabit Technology, Calient Networks, Nexus Photonics, and Quintessent. On top of these accomplishments, he's an impactful educator, giving advice and creating opportunities for many others. More than twenty people from his group have become professors all around the world and more than twenty have started their own companies. Additionally, he started the Center for Entrepreneurship and the Engineering Management Program at UCSB, which evolved into the Department of Technology Management that offers master's degrees, PhDs, and certificates in technology management. He also founded a non-profit, Unite to Light, to make low-cost and healthier light sources accessible to the world, specifically for those places with limited resources.

We are pleased to provide the interview transcript below for others to read and learn from Prof. Bowers' insights.

Prof. John Bowers, University of California, Santa Barbara, United States.

Lin Chang: How did you become interested in silicon photonics?

John Bowers: I got interested in silicon photonics because we were using silicon oxynitride waveguides to dramatically lower the loss of optical waveguides and open up new applications, like optical gyroscopes on chips or optical memory.

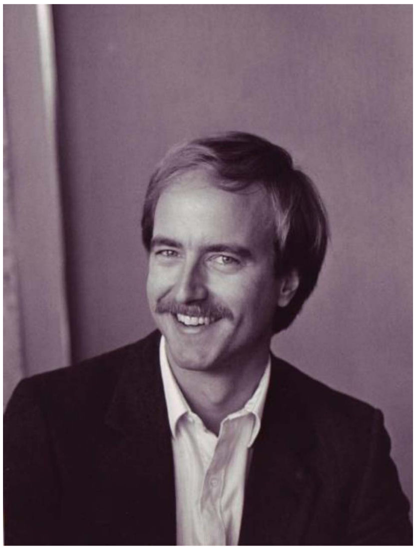
And this is exciting. But this prospect of integrating lasers, modulators, detectors with those waveguides opened up a lot of new high-volume, low-cost applications, like transceivers. The prospect of skipping five or more generations of process technology and using modern packaging to make scalable devices was very exciting.

Chang: Why is silicon photonics so important now? How has your work in silicon photonics been transforming our world for years and how will it continue to do so in the years ahead?

Bowers: There's this very interesting convergence that's happening now between electronics and photonics. Electronics is limited and getting data on and off the chip, and as communication speeds get higher and higher, copper interconnects are really not competitive. They take too much power, require too much equalization and regeneration. So, photonics has moved from simply being used for long-distance communications to connections between racks and now chip-to-chip. The prospect of silicon photonics being used for every high-capacity switching chip, every high-speed GPU or TPU or processor, for high-bandwidth memory is really exciting. Conversely, to make really advanced transceivers, we need electronics intimately integrated with it to lower the power required.

It's a very exciting time. For these photonic solutions to be integrated with electronics, they have to be on silicon, right? So, you match the coefficient of thermal expansion of integrated circuits (ICs) and really take advantage of modern packaging. This exists for iPhones and things. So, no more gold boxes for photonics. I think silicon photonics will transform our world in the future, because it opens up these high-volume, low-cost solutions to not just transceivers and telecommunications, but healthcare, sensors, transportation, many applications that traditional photonics couldn't address because they were just too expensive.

Chang: As everyone knows, your work in 2006 successfully bonding III-V onto silicon waveguides has been widely accepted as a milestone in silicon photonics. It was also the start of laser integration of silicon photonics. Would you share some stories behind this work? What kinds of challenges have you overcome to achieve that?



Bowers at Bell Labs around 1982.

Bowers: We had developed bonding for different materials to enable high brightness LEDs (which Rajeev Ram, now a professor at MIT, did) and for high-performance photonic integrated circuits (PICs) at telecom wavelengths. So, this was successful. I was pretty convinced that we could use bonding to get III-V materials on silicon without the degradation and performance problems you get with epitaxial growing materials, or anything with defects in it. The challenge, of course, is that III-V materials are not in silicon foundries, and there's a lot of concern about that. But they're all dopants, and as long as we exist on the copper side of it, I think it works quite well.

Chang: Why do you think laser integration on silicon is so important? Could you also talk about the impact of heterogenous laser integration on silicon photonics?

Bowers: We all learned about the importance of gain when fiber optic networks were transformed by EDFAs (erbium-doped fiber amplifiers). You can make much bigger, much more complex and much cheaper networks by having gain in this optical network. The same thing was obviously true for electronics. Without gain, you really couldn't make an interesting IC. So, while many people around the world focused on silicon germanium for optical gain regions, it was really clear to me that indirect band gaps would never be competitive. They just wouldn't be as efficient as you'd get with indium phosphide or gallium arsenide technology. To integrate laser and silicon photonics would require direct band-gap material. We originally called the first work "hybrid integration," but now, more properly, "heterogeneous integration" of indium gallium phosphide and silicon. And again, gain regions with a lot of defects in it don't typically have good performance, high efficiency, or high reliability. By bonding materials that we grew on pristine materials, on epitaxial wafers, allowed us to get into these large wafer sizes, much larger than gallium arsenide or indium phosphide could do by themselves.

Chang: Do you think heterogeneous silicon III-V lasers have reached commercial availability?

Bowers: Yes, it has. Intel has certainly led that and they're doing millions of transceivers a year. And, Juniper (now Openlight) has pursued that. So, I think it solves a lot of problems. If you look at Infinera, a very successful photonic integrated circuit company, they typically have five or six epitaxial growth steps to make lasers, modulators, detectors, or to integrate contacts with waveguides. So those five or six regrowth steps are costly, and yield limiting. But with heterogeneous integration we can bond all the materials at one time and process it all together. So that's a real advantage. Plus, we can get much wider gain widths. We can combine visible devices with infrared, with far infrared devices all in the same PIC. I think heterogeneous has really solved a lot of commercial problems needed for high-volume, low-cost applications.

Chang: After the initial work, you continued to lead our group and made many other breakthroughs in silicon photonics. Could you talk about several important ones?

Bowers: Well, probably the most important one is the one that we did together, that you really led, namely making initially highly confined waveguides and lithium niobate for second harmonic generation, and then moving on to gallium arsenide. And again, the fact that you have this strong confinement makes the lithium niobate devices work better than our native substrate. And same thing when you put gallium arsenide on top of silicon with SiO_2 all around—then you get very efficient second harmonic generation, very efficient comb generation, much better than you would get on a native substrate. So heterogeneous on silicon works better than on gallium arsenide, or on lithium niobate substrates. It's very exciting.

Once we integrate lasers with these devices, then you get interesting comb sources, and get very narrow lines with lasers. The Lorentzian linewidth was at less than a tenth of a hertz already, and I think we can get to a millihertz. And so again, combine the very low loss of what you can get with waveguides and silicon, with now gain or nonlinear devices, and it makes much better devices. We started trying to make lasers that were as good on silicon as on native substrate. But now we can make better lasers on silicon than on native substrate.

We always think of semiconductor lasers as being noisy, much worse than a gas or solid-state laser, but now they could be lower noise, and that'll open up a lot of new applications.

Chang: You mentioned hybrid integration in one of the previous questions. There have been several different integration strategies. What is your reading of different integration strategies like monolithic, hybrid, and heterogeneous integration for the future of silicon photonic systems?

Bowers with a wafer of heterogeneous lasers integrated with silicon photonics in 2021.

Bowers: Most people use hybrid integration. The lasers may be fiber-coupled to the PIC, or they may be adjacent to each other, and indeed that works well. For making narrow linewidth lasers, that works very well, but it's not a very scalable, high-volume approach. On the other hand, when you go to heterogeneous, when you bond III-V materials onto silicon, you can do all this processing in parallel, right? The laser, modulator, detector integration all happens, processed at one time. The contacts are made at one time. And you get all the advantages of wafer scale testing. I think that's really key for scalable low-cost systems. Eventually I think monolithic will become important. So far, you give up performance and you give up reliability, but it's moving very quickly. Recently, we have been working on epitaxially growing quantum dot lasers on 300 mm wafers, and it works quite well. We can get over 100 mW output and pretty good reliability, but not yet as advanced as heterogeneous integration.

Chang: You mentioned that there has been a lot of progress in the area of integrated narrow linewidth lasers. Why are narrow linewidth lasers very important for silicon photonics?

Bowers: The obvious applications are coherent communications, particularly as we move to higher levels of QAM. And in general, optical gyroscopes need narrow linewidth lasers, spectroscopy needs narrow linewidth lasers. Linewidth is sort of a metric for lower frequency or phase noise. What we've seen by integrating DFB (distributed feedback) lasers with resonators is that the frequency noise and phase noise come down by literally 70 dB or more. That has a lot of advantages for a variety of sensors, certainly spectroscopic devices and others. Microphotonics works much better by pushing down that noise, and I think it's really important.

Chang: You have also mentioned microcombs. As we know, microcombs over the last few years have become a very hot topic, and you are one of the leaders in this direction. What do microcombs bring to silicon photonics?

Bowers: The first is certainly just as a comb source. By having literally hundreds or a thousand wavelengths that are very precisely spaced from each other, I think is really important. I think you can do things like dual-comb spectroscopy by having two combs that are slightly different, and the repetition rate opens. It's much better than traditional spectroscopic measurement systems, and so they can be compact, low cost. And I think we'll find a lot of applications. It's a really exciting area.

Chang: Could you talk a little bit about our recent demonstration of the optical frequency synthesizer and atomic clock by using silicon photonics? Do you think that in the future we can integrate entire such systems on chips?

Bowers: Sure. Most optical systems today use one laser or a couple of lasers. In that case, you have different options. But the point of that recent paper was that using a comb source with tens of hundreds of tightly controlled wavelengths combined with fairly complex silicon photonic PICs allows us to demonstrate very high-capacity communications—two terabytes in the case of the *Nature* paper—or also very complex microwave photonics, which was also there. So, Lin, you led that effort and made it successful. I'm glad I was able to support it.

Chang: Thank you. There has been another work, a paper you've just published in *Nature*, in collaboration with Nexus Photonics, which has also overcome a longstanding bottleneck in silicon photonics. Could you talk about this work, and how it will affect silicon photonics in the future?

Bowers: Most silicon photonic works use silicon waveguides, and all the datacom and telecom and 1.5 microns. But silicon is absorbing as you get into the visible region. The *Nature* paper with Nexus Photonics is about silicon nitride waveguides and integrating shorter wavelength gain regions. I think what we've done beginning and now with Nexus pushing 980 nm wavelengths, and then shorter wavelengths in the future, it opens up a lot of new applications. It's essential then to have gain coupled to nitride waveguides, not silicon waveguides. In a sense it's a much harder problem, because III-V and silicon are about the same in index. So, coupling between them is fairly easy. But silicon nitride waveguides, particularly a thin nitride, for most of the energy is in the oxide, which is how you get the lowest loss, is an index of 1.5. So, coupling from this 3.5 index to a 1.5 index is a much harder problem. As that paper showed, you can get very efficient coupling (less than a dB loss) and very little reflection from those interfaces. So, for the tunable lasers that were demonstrated there, that's absolutely key to get smooth tuning, not to have reflections at those interfaces. And the really exciting thing about that paper was the lasers lased up to CW, up to 185°C. That allows us to now make tunable lasers that are not limited to room temperature operation, but don't need temperature cooling. With wavelength measurement on a chip, you can again have this laser uncooled and for almost any application. Once you have visible wavelengths, then there are a lot of applications for AR/VR and for atomic clocks and a host of new, important fields. So, I think that was an important paper.

Chang: You have published many works in top journals over the last few years, so could you talk about how the publishing process has benefitted your career?

Bowers: There's a famous phrase, which is "not to keep your light under a bushel basket," so it is important to find prestigious places like *Photonics Research* that many people read to get the word out on what one has done. I think I have published eight papers in *Photonics Research* and they've been highly cited, so I appreciate the widespread readership. A story I've told many students about publishing involves Herb Kroemer, who won the Nobel Prize at UCSB for inventing the double heterostructure laser. The interesting part is that his original paper was rejected. I always tell students, don't get too discouraged if your paper is rejected. Herb's paper was good enough for a Nobel Prize. Fortunately, he didn't give up easily.

The key is to not give up easily, but have your own strong opinion about the importance of the research you're doing. Herb did resubmit his paper. It was published. He did submit a patent, which was issued. So, he got the recognition he deserved. But again, people doing some of the lasers at the time—this is 1962–1963—were not aware of his work, and so it's unfortunate because he could have impacted the field a lot sooner if he had worked in one of the groups that were in that area. But he was working at a different company that didn't do lasers, and so it's important to make sure people learn about your work. Don't keep your light under a bushel basket.

Chang: Indeed, that's also a very important lesson for me and I will also teach this to my students, too. Besides your outstanding scientific achievements, you are also famous for your great success in technology transfer from academia to industry. Could you share your experience on how to commercialize technologies?

Bowers: I don't know that I know how to do it. Many people do it much better than I do, but if you can get a big company like Intel to take up your research and commercialize it, that's obviously the best outcome. Going and giving talks at companies and conferences is really important, but many times you do good research, and no one picks it up. In many cases, it's only the person doing the inventing of the development, like the student or whoever. And then, if no one picks it up, it'll get lost. It doesn't cross that valley of death, and then you have to start a company to get it commercialized. Many times, only the inventors see the value. I've been lucky to work with a lot of brilliant students who took the ideas they developed here and developed them into companies.

Fortunately, University of California is very receptive to licensing the technology to inventors, and they've been very supportive to me. I've taken I think three leaves of absence to look at starting companies. And (the university) has been very supportive.

Chang: Great. Besides those questions, there are also many questions that we received from the audience. Many of them are from young researchers seeking advice for their career. As everyone knows, you are a very good supervisor. There are many people from our group who started their own companies and have become very successful. What advice do you have for researchers in terms of launching start-ups in silicon photonics?

Bowers: Well, I think as Wayne Gretzky famously said, "You should skate to where the puck is going, not to where it is now." If you're going to start a company, you can't do something that's immediately applicable. You need to leapfrog existing companies and technologies and make a breakthrough. While you're building the company, everybody else is progressing, so make sure it is a breakthrough, and then pursue it vigorously. Great ideas are important, but you have to assume that other people have thought of it too, and so you have to move very quickly to implement it and do it tenaciously. You can't give up. There'll be a lot of down moments, and so anticipate that and just pursue it very vigorously.

Chang: There are more than twenty people from our group who have become professors. If you were a graduate student today, given today's support for R&D, would you opt for an academic or industry career?

Bowers: I've been lucky to do both. I started at Bell Laboratories and really learned a lot there and worked with a lot of great people. And I've been lucky to be at UCSB, and they've given me the chance to kind of cross the line, and take probably a total of about four years leave of absence. Both directions are ways to change the world, and that's what's important. The choice of academia or a company really depends on what you enjoy doing. I enjoy teaching. I get a lot of pleasure of seeing students become successful, and I'm very proud of what you've accomplished. I take pleasure in that, so an academic career works really well for me.

Chang: In terms of academia, do you have any suggestions for people who want to pursue a faculty position?

Bowers: One thing is certainly to do a good post-doc. In many cases, you can go directly from a PhD to a university, but it's difficult to get a really good academic position. You could be with a lot of other people, right? A good post-doc can help you get a better position at a better university than you might otherwise get. But in general, just throughout life, just keep learning. Don't get stuck in a rut, basically. If you stay and do a post-doc where you did your PhD, make sure it's on something a little different and something you can learn from.

I was a grad student working in solid-state physics and in the zinc oxide world, again on silicon, taking piezoelectrical materials and putting them on silicon. But as a postdoc, I was working in the fiber optic field, and so it was a big change for me. I learned a lot, and that really gave me a leg up when I went to Bell Laboratories.

Chang: Indeed. Another interesting question is that, in addition to being a great scientist, you are also a great bicycle rider and snow skier. I recall that you went across the whole U.S. riding a bicycle. How did you become interested in these hobbies and how do you maintain work-life balance?

Bowers climbing with his granddaughter Emma in Colorado in 2022 (left); Bowers backpacking in California around 2010 (upper right); Bowers skiing at Vail in 2022 (lower right).

Bowers: Well, in that case, I saw a movie about riding the Tour Divide, which goes from Canada down to Mexico along the Continental Divide, so that got me interested in trying that. I think the point is that to sustain yourself over the long run, you have to remain healthy, and not allow work to run you down, not let your health degrade. Exercise is really important to maintaining vitality. When I was younger, I used to run and play soccer and tennis, but my knees are not in such good shape anymore. So, biking is a way to stay in shape. I do remember when I was at Bell Labs with Tom Wood and others, we used to run at lunchtime every day. We were coming back after that, there're about ten of us, and our boss was kind of irritated that we were all off at lunchtime running. They asked us where we ran, and Tom Wood was smart, and he said, "Well, we only run as far as you can get to in an hour, so we keep it during our lunch break." But yeah, whatever you choose is fine, I think.

Chang: That's a very interesting story. And finally, do you have any other advice for young researchers today?

Bowers: Find something you're passionate about and pursue it relentlessly. Become the very best at something. That's certainly the expectation for anyone when they get a PhD, that by the time they graduate they know more about that topic than anyone in the world. It takes hard work, and you have to expect that you're going to be frustrated and have a lot of downturns. But just have the vision that what you're doing is the right thing, getting a PhD or pursuing a particular idea. So, change the world. You can work on something very broad, or it could be very narrow, but do something that will have an impact. Sometimes, when students ask about a topic, I'll say, okay, fine, maybe you're right that will work and it will be successful, but is anybody going to care? Make sure you choose something that really will impact the world. And we all only have a limited amount of time on this planet, so it's important to make the world a better place with the time we have.

Chang: Thanks, John. We really appreciate that you're sharing all those valuable experiences and insights. I'm sure that many people today will benefit from them, and also in the future. Thanks again for spending your time for this interview. I look forward to more exciting news of silicon photonics from our group in the future.