Interview with light-wave architect Jelena Vučković

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Mengjie Yu (University of Southern California) (right) interviewed Jelena Vuckovic (Stanford University) (left). Access the video directly at https://doi.org/10.1117/1.AP.6.4.040503.

Mengjie Yu: Hello, everyone. This interview is organized by the journal *Advanced Photonics*. And today we're really honored and privileged to have Professor Jelena Vučković from Stanford University here with us. I'm from University of Southern California and will conduct the interview.

Let's just start with some questions. So, hi, Jelena. I think I actually heard from my advisor that you were very into music and architecture when you were young. So, it's kind of interesting that you choose electrical engineering as your major in college. Maybe we can start with that as a question: What is the reason you wanted to pursue a PhD in this field? Maybe you can share some thoughts with us.

Jelena Vučković: Hi, Mengjie, good morning. Some background: Mengjie's advisor is Marko Lončar from Harvard, who is my good friend.

I grew up in Serbia (in former Yugoslavia), and I went to high school that is specialized in math and physics. But I had pretty broad interests—I was interested in music, and I played an instrument—flute. But I was also interested in listening to music, alternative music—that's what Marko was talking about. When I was in elementary or middle school, I even thought about being a music journalist. But the profession that I had been interested in since kindergarten was architecture, which combined my interest in the arts, and math and engineering.

I preserved interest in architecture till the end of high school, and even considered studying it after graduation. Back there, you had to pick your major as soon as you finish high school. You have to enroll in a particular major from day one (of college). A couple of weeks before the university entrance exam, I decided to study electrical engineering. This was not a very obvious choice back then, because I didn't see all that creativity that I saw in architecture right away in electrical engineering. But my older brother was studying electrical engineering, and he relayed to me that there was a lot of creativity there. It certainly links very closely to my interest in math and physics, and I decided to give it a try.

Back there, kids who are good in math and physics generally went into electrical engineering because that provided more career opportunities. I didn't regret the choice, but it took a while to realize that it is, equally, if not even more creative than architecture, as that aspect was not as obvious to me. As you can see from my (Zoom) background, I feel that there is a lot of art in what we do. And all of this design of photonics, is beautiful and creative. But of course you don't see that creativity on a large scale, like with architecture. Instead, you need to learn more and wait a little bit longer until you see that level of creativity in photonics, or in electrical engineering. But it's there. It's just harder to articulate that to kids who are thinking about what to study one day.

Mengjie Yu: That's right. Yeah, so I guess your background is actually also a beautiful architecture on the nanoscale. We'll get to that later. Yeah, I think you shared a lot of similarities in terms of music with Marko as well, because I think Marko mentions music is like acoustics, you know (he's really into music) and acoustics really kind of inspiring opto mechanics in diamond.

Jelena Vučković: Exactly—it's all about waves. The important message is that career choices are not always obvious and straightforward for everyone. I had many interests, and all of them came together at some point. I don't think that everybody needs to decide early about what they would want to do. It takes time to figure things out, but all those interests play a role later on in what you do. And even within

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electrical engineering, initially, I was interested in information theory which seems completely disconnected from what I do now.

But my work on information theory was not a waste of time and there is a connection to my work today through quantum error correction. Things come together later on. I tried a lot of different things along the way, but I feel that was important for who I am, today, and what I do.

Mengjie Yu: Exactly. I think I strongly resonate with that. I think it's a very unique experience when you are connecting dots in your life, you know a very amazing feeling.
Jelena Vučković: And it's not obvious right away. In retrospect, things become so interesting and connected and useful—not when you are doing them at that moment.

Mengjie Yu: Right. So just a follow up on that: I guess then not sure whether that's also very planned or not planned. Then why did you choose to become a faculty and choose this academia path as your career path? Is it also kind of a "follow your heart" kind of style, or did you actually plan it?
Jelena Vučković: I got the undergraduate degree in electrical engineering in Serbia. And I was not completely sure at the time when I graduated that academic career, or even graduate school was what I wanted to do. I worked on some software projects, I worked as a teaching assistant—tried different things. But at the end I felt that working as a programmer or just teaching was not as exciting career choice to me.

Best students from my country who were interested in continuing their education were applying for grad school in the US back then, and since I didn't see myself working just with my undergraduate degree, I applied to grad school.

I spent some time in Sydney before coming to California—to Caltech for grad school, doing some research in information theory—error corecting codes. When I came to Australia, that was the first time when I started properly doing research. And although that's much more applied math than physics that I'm doing now, I thoroughly enjoyed it, and realized this was something I would consider doing in my life.

At Caltech, I decided to do work on photonics and quantum optics, and that choice again was not as obvious. I met my former advisor, Axel Scherer, who was also Marko's advisor. Those were early days of photonic crystals, and Axel's group was the first group really making photonic crystals. I didn't know anything about nanofabrication.

I remember Axel saying: "You could do theory anywhere in the world, but since you are here at Caltech, why don't you try to do an experiment? Because you don't have this opportunity everywhere." And I thought—this seems very interesting. It looks like something where I would learn a lot, and I would enjoy it and that's how I picked that area. But then it was also not clear whether I would go to academia after I graduate. Grad school was going well, and I was really enjoying teaching, so I volunteered to teach many different classes. I was a teaching assistant pretty much every single year that I was at Caltech: for solid state physics, quantum electronics, semiconductor devices, nanofabrication, a variety of classes. I really enjoyed it, but I didn't want to be only a teacher. I was also good in research, and towards graduation, it made sense that academic trajectory is really what I should be doing. At the same time, I graduated in 2002. That was a time after dotcom bubble burst. There were not many jobs in industry.

I also mentored undergrad researchers while I was at Caltech. One of them, Ilia Fushman, later came to grad school at Stanford and became one of my first graduate students. Combined interests in research, teaching, and mentoring made the choice of academic trajectory obvious. And I enjoy the variety of things that you can do when you are in academia. You can be a teacher and a mentor and an advisor and a researcher. And you have control over what you do. If you would like to teach more in some part of your life, you can do that. If you want to do research more, then you can do that as well. I don't see any other profession where you really have so much flexibility and control over what you do, and where you can shape your profession.

Mengjie Yu: I think it's a really good overall perspective of a role as the faculty. I think you really have to have a strong faith in terms of education, teaching, mentoring, and curiosity for science. I think those are very important.
Jelena Vučković: Indeed, it is not just research. We are hired as faculty based on our research achievements, of course, you know, that's what's on our CVs. We're not trained to be mentors or advisors, or even teachers primarily, but in this profession, all of these aspects matter so much. Because you have to do fundraising, you have to manage your group, you are entrepreneur in some way, because you advise your students. And that's very important, for students who are considering this career to keep in mind—that it's not just research. You have to enjoy all of these other aspects in order to enjoy the job.

Mengjie Yu: Yeah, I totally agree with that. So maybe we can move to the research topic in your group. You are really the leading expert in integrated photonics, quantum photonics. So my next question is, what is your vision regarding the future of integrated quantum photonics? Let's say, in the coming decade or so.
Jelena Vučković: In quantum technologies, there are exciting things happening right now in experiments. It's still not at the level of practicality that we see, for example, in classical computing platforms—GPUs and AI hardware, but in quantum (space), people are building larger scale systems that are capable of solving interesting physics problems, and are working on discovering new algorithms that would make these platforms more useful. And leading quantum hardware platforms (even those based on atoms or superconductors) have photonics bottlenecks. In the superconducting platform, you need quantum transducers to link processors into a network. In atomic physics platform, you need better spatial light modulators, or miniaturized lasers—new classical photonics for controlling these atomic systems. That's one aspect of quantum technologies where integrated photonics is playing an important role, but that's classical photonics solving bottlenecks in all of these technologies. But at the same time, if you're looking at the development of classical computing hardware and just in general, the technologies that are broadly used today, eventually you have to go to an integrated platform. And the platforms that we're most excited about are based on optically interfaced spin qubits in wide band gap semiconductors. They're not as mature as the other quantum platforms (atomic or superconducting), but they already play important role in transduction, quantum networking, also quantum sensing. I strongly believe that optically interfaced spin qubits platforms (where of course quantum photonics is playing very, very important role in manipulating and entangling these systems and communicating information between different qubits) will eventually become the leading platform because of the suitability for integration and scaling. Recent developments in diamond and silicon carbide in particular are making me very optimistic about this platform being suitable for scaling to a large number of spin qubits that could be used for quantum simulation or quantum computing. It's not just distributed quantum networking, or quantum sensing anymore, but a platform where you can build gate-based quantum computing on spin qubits, which are optically interfaced. I think that 10 years from now, we will see quantum simulators, and even gate-based quantum

computing with optically interfaced spin qubits. Whether it's diamond and silicon carbide or something else emerges, we'll see.

Mengjie Yu: Got it. So you mentioned scalability? I think it's a really important thing. So like, do you have a number, you think in 10 years how many spin qubits?
Jelena Vučković: That's very hard to answer. and difficult to speculate. In these particular platforms, we're right now in the range where we have 10 qubits with all to all interactions inside of a resonator, and that we can potentially use for small scale quantum simulation. I see a trajectory in our university lab, of going from 10 to maybe a hundred. And then beyond that, it's not something that we should be pursuing in a university lab anymore if it becomes successful. At that point, there would be technological challenges that are simply not good PhD topics anymore.

But reaching 100 qubits on these platforms is already an interesting size of a quantum system, and I am optimistic they could be scaled even beyond that, but this remains to be seen. At the same time, quantum computing and quantum technologies in general are very exciting area of research. People are already solving interesting physics problems, but finding algorithms where potentially these systems could be used to solve something more broadly useful (apart from Shor's algorithm) is still an active area of research.

Mengjie Yu: Yeah, that's right. I guess we're looking forward to seeing the future development from your group.

You mentioned an interesting thing about transition from the concept of commercialization, transition for university, a prototype to a large-scale industrial system. So that actually leads to my next topic about this idea of inverse design—you already have a startup, or your students already have a startup company based on this. And actually, this concept, we noticed you actually worked on from very early on, like 2011, I think, with Jesse Lu, and that really made a big impact in the field, in the recent decades, already. So, my question is—I guess I have two questions. One is how did you come up with this idea? And the second is, I see you put all this open-source PDK?
Jelena Vuckovic: There were a few questions there, so I'll answer them in order. First, the idea of inverse design. When I was in grad school (that was a time of photonic crystals), at some point we realized that in two dimensions you need to pay more attention to how you're designing resonators to achieve high Q (quality factor). So I started working on optimizing the arrangements of holes in order to improve Q factor of photonic crystal resonators (also collaborated with Marko on that). When I interviewed for a job at Stanford in 2002, one of the people whom I talked with was Stephen Boyd (later my collaborator), and he's one of the leading figures in convex optimization. He noticed my paper on optimization of photonic crystal cavities, and we started talking about it at my interview. Quickly I realized that my view of optimization was different from that of optimization experts. Stephen later became my good collaborator, and some of the early papers we published with Jesse in 2011–2012 involved Stephen who explained to us details of optimization algorithms. But even before 2010 with the first generation of my students, we also tried to do some work on analytical inverse design: start from desired field, invert it back to profile of photonic crystal resonator. That was the work we did with Dirk Englund, who is now a professor at MIT, and Ilya Fushman, and then an undergrad Joel Goh (who became a faculty in business school later on at Harvard, and now he's at the National University of Singapore) who did his senior thesis on genetic optimization of photonic crystal. That was around 2005—early years of my group. And at that time we started thinking about optimization—convex optimization, but were not completely sure how to apply it to those problems. It took us about 5 years, and that's when Jesse Lu joined, my first student who graduated on this topic. He worked also closely with Stephen Boyd and that's really when we figured out how we could actually apply optimization algorithms to electromagnetics and search the full parameter space in three dimensions. It was not just moving a few holes (what we and others were doing before, which are much simpler problems, and where you can also use algorithms like genetic optimization), but truly searching the full parameter space.

The idea of finding the optimal design for achieving a particular function is something that I've been really thinking about since grad school. And in part it was also driven by the fact that I didn't like this high failure rate in fabrication, and lack of robustness of photonic designs. It didn't seem like the right way to do things, as opposed to electronics hardware, which is robust to errors. How are we going to scale photonics, if it is so sensitive to everything? And that's really what was driving this idea of better design. And maybe as we were talking at the beginning of the interview, me being an outsider to the field of photonics helped in search of better ways of doing things. Maybe if I had been narrowly trained in photonics as an undergrad, I would be doing things in the same way as everyone else. And that's where this broad training played a role.

It took about 15 years for inverse design to take off. Starting with about 2010, we designed photonics in the full parameter space. After Jesse, several generations of students worked on photonics inverse design, and eventually Jesse started the company Spins Photonics that is commercializing inverse design. That project went through natural process where, initially there were many exciting PhD topics formulated around this. And at some point it became useful, and people were licensing our software from Stanford, and students were answering questions—almost providing customer service. And we realized, we couldn't do this from research group anymore, and that's when the company was spun out.

As a scientist and educator, I'm very happy to see that people are using our software tool, but also I always felt that this is better way of designing photonics, and there is an educational component to this, and science and knowledge should be accessible to everyone, which is why from day one, we open sourced our code. There has always been a free, open-source version of the software—both for the older version of the software, and for the new version of the software, that people from all over the world can access and play with it and build up on it. That's available on GitHub. It's really exciting to hear from students from all over the world who used our software. Our tool is also changing the way people are thinking about photonics.

Mengjie Yu: That's right, yeah. That's really inspiring. I think you bring up a very key concept which I strongly agree with about how to be creative. As a researcher, I value speaking with people outside of a field and having a broader touch of the research from early on and then being open minded. Right? Talk to people who just think about the problem from a completely different perspective.
Jelena Vučković: Exactly.

Mengjie Yu: That really is great advice, I think, for younger generations.
Jelena Vučković: Exactly. And then you have asked a question on the PDK, right? That's a process design kit for the listeners who are not familiar with foundries. Commercial foundries have a design library that others who are designing their chips can use. And in that library there are different elements of the photonic system or electronic system that they can use in their design. Inverse design is changing this, because you can optimize even traditional components, to perform much better—like grating couplers: reduce losses, but also introduce better elements for

wavelength multiplexing (for example the picture behind me) or mode multiplexing, and so on. We are making these inverse designed structures in foundry right now—we can make them robust within fabrication constraints of a foundry. Should PDK be open-source? That's not something that we, as scientists, are making decisions on. But we are providing an open sourced tool that researchers can use to design things.

Of course, there is a lot of IP involved in the PDK, and generally it's not really open-source, as far as I know in any foundry. This is a topic for discussion, maybe for the community, to decide how to proceed.

Mengjie Yu: I see this could be a very nice panel discussion.
Jelena Vučković: I agree with you. This really would require getting people from industry and from academia to sit together and to decide what is the best way to proceed, because photonics is going through a really transformative phase right now–where electronics was, maybe 40 years ago—in terms of scaling and integration. The number of components that we're designing and the number of components that are in integrated systems is increasing. And the library of structures in foundries is increasing.

There are a lot of questions, really good questions here, to which we don't have an answer. For example, how do you even protect your IP when you design something? Is PDK going to be open-source or not open-source? Who holds the IP? Is the patent the right way to protect it? The people in the electronics community went through this a few decades ago. And just because photonics is getting to the point where it's becoming more practical and useful in the communication, even computing systems, and it's used in conjunction with electronic hardware, this is something that we as a community need to make a decision on. We either follow what our electronics colleagues have done over decades, or we make some, new approach.

Mengjie Yu: That's right. Yeah, I will note this down. See what we can suggest to the big conference organizer, since it is a great topic of great interest.

I guess we have limited time. I want to move on to professional development questions. Or I guess we briefly touched that, but maybe want to hear more. So from your personal experience, how to become or stay creative as a researcher?
Jelena Vučković: That's an excellent question. I think it's important to be curiosity driven. Not to follow the latest trends, but do whatever you think is an important question and follow your curiosity. If I look back at my career—topics that I was doing, when I started my group were not really popular back then, such as quantum photonics, integrated quantum optical systems. This is much more exciting to the community now. But I thought that this was a really interesting long-term problem to work on, and I was excited about it, which is why I did it. It is important to be driven by your curiosity and to have that drive, because that's the only way to recruit students and people to work with you. One can't fake enthusiasm.

Mengjie Yu: It sounds easy. Actually, I think it's very hard to do, especially—I chime in with my personal experience as a young faculty, because I think the big environment is different between before and now. Maybe it's not that much difference; I just feel this field is very high paced, highly competitive. So it is actually very hard to really decide on the high risk, high reward things to do, or some like "trendy" things to do.
Jelena Vučković: I agree with you.

Mengjie Yu: So, I'm just wondering, what's your suggestion on that? Because I think if I pursue those high reward things which are long term, or whether that actually puts a lot of pressure on tenure outcomes.
Jelena Vučković: I think it's important to do a combination of things. If I look at my research statement that I submitted when I was applying for faculty positions, it's interesting because it's exactly what I'm doing now.

Mengjie Yu: Is it?
Jelena Vučković: I was talking about using nanophotonic structures to make better lasers, with higher modulation speed. That's what I was thinking about then, mostly in the context of photonic crystals (this was before inverse design).

When I started at Stanford, optical interconnects were not something that I was thinking about, but there was an optical interconnect program back then (chip-to-chip interconnects) and David Miller, my colleague from Stanford, was one of the people leading it, with Krishna Saraswat and Jim Harris—my colleagues from electrical engineering. They got me on board in that program, and I started getting more deeply involved with optical interconnects. And as you know, this is also something that we're working on now. After 20 years, it's practically very useful, and this is something that people also in industry are actively working on—to reduce energy consumption, increase operating speed, connect different cores of a processor, different GPUs, processor and memory. It's everywhere—it's not just to connect different servers. I got into that space because of my surroundings and my colleagues working on it. But then I also found that my interest and my excitement in different problems fits into this.

So you just follow your curiosity, and then you talk to people, you see how that is relevant. You find some problems that are applicable on shorter time scales, and some problems that you can work on for next 20 years (and for me, that was quantum photonics, and I'm sure I can work on it for the next 20 years). I like to work on a combination of problems that are closer to basic science and problems that are closer to applications and technology.

I also went through a little bit of transformation in my career. Initially, I was more interested in basic science, coming from Caltech, which was not as entrepreneurial or driven by practical applications as Stanford was. Coming to Stanford and especially being in electrical engineering department, made me think about problems differently. And I also found more beauty and appeal in doing things that would be useful for others, not just for discovering basic science. We also evolve as researchers.

Going back to your question: try to work on different problems; diversify your research portfolio, but still stick to your curiosity and interest.

Mengjie Yu: Right. Yeah, definitely thanks for sharing the story. I think I heard many stories from different professors, but they all actually come to the end that you have to work on the problem that you think is very impactful, you think it's really important, like in your story. I remember I heard from Michal Lipson like that she worked on silicon photonics when nobody believed it can be used for optics. And Marko told me he wrote lithium niobate in his research statement when no one had shown it can be etched nicely. That now becomes something realistic and impactful, I think, or it comes to the end. I think you really have to believe you're working on the most important problem, the most impactful problem.
Jelena Vučković: And some of these problems may become the most impactful problems, right? Instead of jumping on something that already everyone works on, think about the future and work on problems that maybe others don't see yet as important. You also have more time when you work on something that not everyone is working on yet. You have more space. And it's not such a big race with industry and every single group. This is a good place to be as a young researcher because there is not so much pressure.

Mengjie Yu: Sure. Yeah. Good point, that's true. And then I guess science can also connect the dots, you know.
Jelena Vučković: Exactly.

Mengjie Yu: It will be really nice. If you create a new field, it will be really amazing.
Jelena Vučković: Yeah, absolutely.

Mengjie Yu: Thanks for sharing that. We talked about advice for younger faculty. Maybe we can hear a little bit about the advice for PhD and postdocs; maybe you can share your criteria of hiring PhD and postdocs into your group. So people can get idea about what skills are important.
Jelena Vuckovic: As a young faculty, when you hire students and postdocs, you are closer to them in age, you work with them on a daily basis in the lab, and you're basically hiring your lab mates. That was my criterion when I was hiring my initial group of students and postdocs who are all super successful, full professors at MIT, Caltech, EPFL… I mentioned Dirk Englund, then Andrei Faraon from Caltech, Hatice Altug from EPFL—those were my early students. Edo Waks was my first postdoc, and he is at the University of Maryland.

Mengjie Yu: I know. It's amazing to see your first group photo.
Jelena Vučković: Yes.

Mengjie Yu: It blows my mind!
Jelena Vučković: And I mentioned Ilya Fushman also, who is a partner at Kleiner Perkins. They're fantastic people, of course. It is so exciting to see how their careers developed. But when I was hiring them into my group, I was looking into hiring lab partners. I can work with these people on a daily basis, and they have that drive. When you're starting your group, these super talented students and postdocs are also looking for new topics to work on. They want to be on the leading edge of the field. And those are people who are willing to take risks: work with an untenured assistant professor who has some ideas that nobody else is working on. They go into that new trajectory with you, and work with you. There needs to be a lot of mutual trust.

Of course, as you become a more senior faculty member, you have more and more commitments: committees and teaching, and all of that. And your group naturally grows. But I am still looking in these potential candidates that drive that I was searching for in the initial group of people.

Sometimes I hire postdocs from very different areas, who are interested in learning something new. Coming from a different field brings something new to the group, and is refreshing. These people bring a new way of doing things—what we're talking about at the beginning of interview, and I like that. It's refreshing for the whole field - taking risks by hiring people who are maybe a little bit tangential to what you do, but they end up bringing some new perspective into your field.

Mengjie Yu: Yeah, nice. I think we are near to the end. Maybe I have one last question. I'm just gonna change my question, because I just suddenly thought that might be interesting. So do you do miss being in the lab, or in the cleanroom doing things yourself still?
Jelena Vučković: I definitely miss being in the lab. Not so much clean room—as I was saying, I always wanted to minimize the amount of time in the clean room, and this is how inverse design started. I did my share of fabrication certainly (we all did in Axel's group), and even built some fabrication equipment as a student. That was all great experience. We can ask professionals to do (like a foundry) whatever we should be doing—we don't really have to do it ourselves. But at the same time, getting trained in fabrication, I think it is an important aspect for students and postdocs, and I still encourage them to do that. Because even if you end up being photonics designer, if you went through whole nanofabrication training, you know what can be done and what can't be done. You understand the process so much better.

But I do miss being in the optics lab. I am trying to be on top of things. I'm not turning knobs myself, but I still go to the lab, help students, tell them which knobs to turn. I'm proud that I still know what's in the drawers and cabinets in the lab.

Mengjie Yu: Really?
Jelena Vučković: Yeah, I do. I'm trying to enforce updating our database of the equipment. But I still know which lenses we have.

Mengjie Yu: That's impressive.
Jelena Vučković: That's my way of being with up of things. I feel that I'm not completely disconnected, if I know where things are. When I was a department chair for a few years, I told my students and postdocs to remind me if they see me drifting far away from the lab. I stepped down as chair almost a year ago, and over the past year, I tried to get closer to research and problems, and contribute more. We're hired as researchers. Ultimately, this is why we decide to go this way. That's what we do before we're hired. Our job has many other different aspects that take our time—fundraising, mentoring, teaching. We have to do all of that. But at the same time, we enjoy doing research and going back to the lab is important. And after all these years, 20 plus years, I still enjoy doing it. And that's the sign that I picked the right job.

Mengjie Yu: Yeah, thank you. I think those are all very inspiring comments and stories and interesting facts about you, and thanks for sharing that. I think we are almost hitting our time limit. So at the last thanks for the organization of *Advanced Photonics*, so we have the opportunity to speak with Jelena today. Then that concludes our interview. Thank you!
Jelena Vučković: Thank you, Mengjie.

Mengjie Yu is the principal investigator of The Yu Group Integrated Nonlinear and Quantum Photonics Lab at USC, where she is a Gabilan assistant professor. She earned her bachelor's degree from Zhejiang University in optical engineering (2008–2012), and her PhD at Cornell University, in electrical and computer engineering (2012–2018). She also completed a postdoc at Harvard University in the School of Engineering and Applied Science (2018–2021).

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