# The Future of Communication: Nanotechnology and Light

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There was a time when a group of humans used to signal other groups by either lighting fire or blowing a trumpet. As we evolved, the mode of interaction between societies improved. We started using pigeons for information sharing, some used them to share king's secret and many used them for their love letters. Later, post-cards were introduced marking our entry into the era of first formal mode of communication. Finally, Marconi changed the entire situation by inventing the first electronic form of interaction, the telephone. Connecting Delhi to Bengaluru was no longer a dream and the exhaustive process of writing post-cards swiftly found a place in grandfathers' night tale. However, with time we realized just voice exchange is not enough for numerous commitments and a more comprehensive mode of synergy became a necessity. What if you wanted to text or video call or e-mail or send pictures of your dog?

Normal telephones couldn't deliver because of two reasons; the device had only number pads that couldn't do anything else than dialling numbers, and wires used to connect telephones were not capable to transmit information other than voice signals. So, two types of revolutions were needed. One that can change the telephone device processing capabilities and second that can make the connecting wires competent enough to carry several formats. And indeed, these two revolutions did happen. One we know as 'Transistor' invented by Bardeen, Shockley, and Brattain and the other Optical Fiber Communication pioneered by Maime, Payne, and Kao. The revolution was so massive and significant that almost all the celebrities listed above were awarded the Nobel Prize.

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Now we use cell-phones, building block of which is a transistor, and the cell-phones over long-distance networks are connected by optical fibers. These two revolutions have made it possible to connect from India to America with the click of a button. The optical fibers go underground and under oceans to reach out to anyone, anywhere on earth. Your cell phone has millions of transistors on a single chip processing the information and there are multiple chips working together for you to make video call or attach a document with your mail. With these two revolutions and efforts by scientists for constant improvements, we can now enjoy variety of experiences that our ancestors had never thought of. You see any electronic components around, either transistors or optical fiber networks or a combination of both are working in the background.

But when was the last time humans settled on anything for good? The more we evolved the more hungry we got for even better quality entertainment and data. We don't just want to watch cricket/football matches anymore; we cravefor High Definition (HD) videos, we are not satisfied with 3G but want 4G or above; we are dissatisfied with 1080p YouTube videos and slowly moving toward 2440p and higher quality videos. The more superiority of service we desire, the faster the device and broadband - the communication channel must be. Since the fiber channels works at ultra-high frequencies, it can handle vast amount of data without breaking down. But what about the device? Will the data transfer between the transistors and between chips our demands, and with stand the ever-growing pressure for quality and speed?

The answer is a big NO!

And the reason has already been taught to us in our basic electromagnetics course. The chips are located on a printed circuit board that uses copper wires to spread the information. Several chips are connected by the help of well-placed and complicated routes of these copper wires so that different chips can connect to each other. But as the appetite for speed and quality is intensifying, the copper interconnects are required to carry more data. In technical terms, the copper connections are required to operate at higher bandwidths, or higher frequencies, while maintaining error free operation. The problem with metallic connections like copper is that they exhibit something known as 'Skin Effect' at higher frequencies. This effect makes the electronic energy to flow at the surface of the metallic wire. One severe manifestation of this effect is leaking out of the data in the form of radiation. The radiation not only reduces the data power being transmitted but also interferes with the other metallic wire connections running between the chips.

To overcome this issue, two lines of thoughts originated within the research community. One wanted to keep improving the current interconnects by exploring the material used to make interconnects or coming up with more advance signal processing units to nullify the effect of information loss. The other group wanted the interconnects to be future proof and advocated for a paradigm shift in the way chips communicate with each other. They advocated for what is frequentlydescribed today as 'optical interconnects' and have since transformed the way the entire industry looks at the problem. We are already using optical fibers to connect continents, have profound understanding about its technology and have expertise to remain future-proof for many decades.

However, reducing the size of optical components to fit on a chip and develop strong technological framework to produce reliable optical interconnects is not as easy as it sounds.

There must be a complete hierarchy of functional units to make the interconnect work and each functional must add any additional benefitsin the existing electronic systems.One major advantage that optics brings to the circuit is 'wavelength'. An intrinsic property of any electromagnetic wave, wavelength is something we never talk when discussing about electronic circuits. Just like electrons carry the information in any electronic circuit, photons carry the information in optical circuit where each photon is identified by its wavelength. Several wavelengths can be used to carry the information and hence this mode does not suffer from bandwidth issues.

Since so many wavelengths are involved, a wavelength selective device is a mandatory requirement to select a wavelength and direct it to its intended receiver. We work towards designing, fabricating, and demonstrating such wavelength selective devices. Now the term wavelength selective might sound a difficult scientific term to understand but in fact it can be understood by what we already know from our senior secondary physics class days. In the Young's double slit experiment, one coherent wave was passed through two small holes followed by a screen. Whenever the path length difference was odd multiples of pi, we got a dark fringe and whenever it was even multiple of pi we got a bright fringe. These odd and even multiples define whether light wave destructively or constructively. We use the same principle with the only change that wave interaction is now happening on a nanoscale device and the double slit is replaced by a ring resonator. The ring has two waveguides evanescently coupled to it and the waveguides carries all the wavelength required for the communication between chips to take place.The transmission port of the resonator shows power-nulls at the wavelengths satisfying the resonant condition and the drop-port of the resonator shows power-peaks at the same wavelengths.

Ring resonators became the most popular choice amongst researchers and industry alike for their versatility. However, there were certain issues that came out with practical resonators. Since the waveguides are nanometre in dimension and tightly confine the light inside them, any roughness appearing on the waveguide walls will inadvertently lead to scattering of light and hence a total loss in the power. A close analogy will be a very fast flowing water in pipes. If there are tiny holes in the pipe along the length of the pipe, water will slowly seep out resulting in a net loss of the water output. In resonator, these scattering points lead to excitation of unwanted modes that start interacting with each other and cause the resonance to split in two notches. A resonator that was supposed to work at a wavelength is working at two other wavelengths and not at the intended one. The two wavelengths cannot be predicted by an engineer while designing the device and can only be detected once the device has been made. This has led to a deep concern among research fraternity and has been an unsolved problem for many years.

We came up with a very counter-intuitive solution where we knowingly split the resonance in two wavelengths. We model the cavity in such a way that the modes generated by scattering points decay quickly in the cavity whereas the extra mode that we desire to excite has enough power to interact the conventional mode of the resonator to split the resonance in two wavelengths. In this way, we solved the long-standing problem of resonance splitting in a Silicon resonator. In simplest terms, we intentionally create defect in the resonator to make it defect-free!With this solution, we don't need to predict the splitting before the device is made. We make the device and then just engineer the property of light in the cavity post-fabrication to get the desired resonance wavelength.