The need for speed

Overcoming the bottleneck in optical data transfer

- In high-speed communications, very fast optical signals connect to your office or even your home. But these optical signals have not yet reached end-of-edge terminals such as personal computers and smart phones.
- The prohibitive expense of optical modulators – devices that create very fast optical signals – limits their deployment to personal edge terminals.
- Dr Hideaki Fukuzawa and Mr Takashi Kikukawa (TDK Corporation, Japan) show that it's possible to make these optical modulators with standard semiconductor industry processing, significantly lowering costs and creating more compact devices.
- Importantly, these modulators can operate at visible light instead of conventional infrared light. This allows further reductions in cost, device size, and power consumption, further expanding the versatility of their application.

The fastest way to transmit data from one place to another is through optical signals. This includes fifth generation technology, 5G. So far, however, this has been limited to the longer distance shuttling of data in communication networks, for example, between base stations – the main network transmission and receiver points – or between the base station and, say, your home. To get the information to your personal computer or smart phone, Ethernet, Wi-Fi, or Bluetooth are needed because the technology required to modulate optical data with very fast speeds are too expensive to deploy at that level. The lack of economically accessible optical modulators has become a bottleneck in a communications industry characterised by a need for speed.

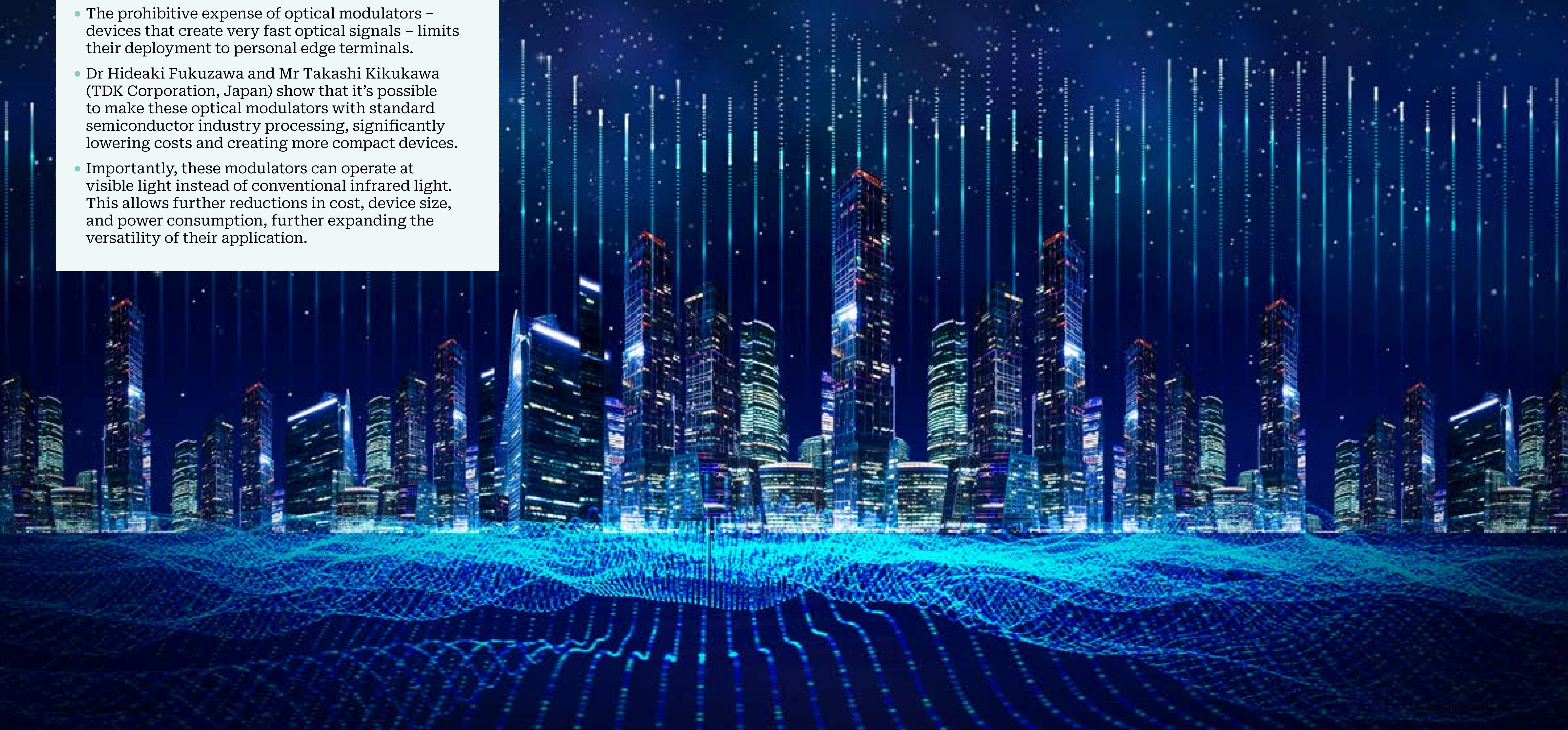
Now, a research team at TDK Corporation in Japan, including Dr Hideaki Fukuzawa and Mr Takashi Kikukawa, have produced optical data modulators using conventional semiconductor fabrication processes, thereby significantly reducing the cost. What's more, the researchers demonstrate that their modulators can operate within the visible light spectrum of red, green, and blue. They explain that this 'opens a new window' for ultrafast data transfer and consumer applications.

> **Visible light modulation can 'open a new window' for ultrafast data transfer and consumer applications.**

Writing on light

Modulation encodes data into a carrier signal, such as shifts in the amplitude, frequency, or phase of a light beam or radio wave. This data could be anything – from text or sound to a movie.

One approach to modulating light signals switches on and off laser light directly. But again, this has limited speed – to around a few Gbit/sec. Lithium niobate is a popular material for external optical modulators for high-end, long-haul optical communications because its optical properties change significantly in response to an electric field with several tenth Gbit/sec or even up to a hundred Gbit/sec, which is



much faster than Ethernet, Wi-Fi, Bluetooth, and direct laser light modulation. It also has other practical attributes, such as a large bandwidth, and high temperature stability. It even has the unique feature of high transparency to visible light.

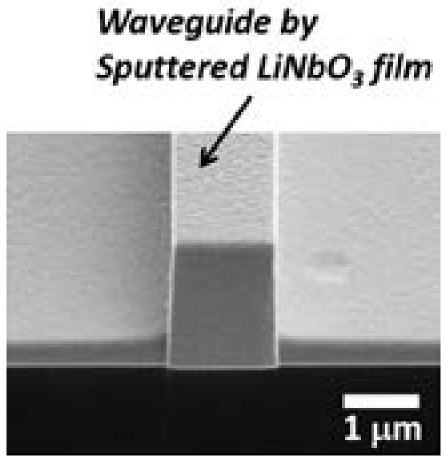


Figure 2. Scanning electron microscope image of lithium niobate waveguide.

Lithium niobate: beyond 5G

So far, lithium niobate has proved difficult to work with for fabricating chip-scale features. Conventional lithium niobate has been fabricated by bulk devices, is very expensive and unsuitable for large volume production, and in addition, the device size is too large to be implemented in personal edge devices. To solve the issue of large device size, many researchers have adopted 'adhesion processes' that stick the bulk lithium niobate materials on wafers, but these are generally clunky and expensive. As the TDK Corporation researchers point out in their latest report – for consumer applications above all, 'a significant cost reduction will be necessary.'

To tackle these issues, TDK Corporation's Senior Manager in charge of optical devices for AR/VR glasses and beyond 5G optical communications, Fukuzawa, teamed up with Kikukawa, TDK Corporation Manager for lithium niobate devices. Exploiting their collective expertise, they were able to produce high-quality lithium niobate optical modulators using one of the standard processes in the semiconductor industry – sputter deposition for lithium niobate film.

Sputter deposition is a general method which has been widely used for many consumer devices including semiconductor devices. It is suitable for large volume production and consumer use applications, and is much more practical than adhesion process by using bulk lithium niobate. For the first time, the TDK team have successfully achieved optical modulation using sputter deposited lithium niobate film directly onto a sapphire substrate. X-ray diffraction of lithium niobate reveals that it is good enough to be used for optical modulation.

Seeing the light

With the lithium niobate sputtered film on a wafer, standard semiconductor fabrication processes (such as etching) can be used to shape a waveguide and deposition for the electrodes, creating a functioning optical modulator device. This means that from the beginning of lithium niobate deposition to the end of modulator devices, the general semiconductor fabrication process can be adopted, making it far more cost-effective than the conventional method. Importantly, their modulator had another key distinguishing feature. They specifically designed the device to operate at visible wavelengths of light including red, green, and blue light. This has never been previously attempted for devices used in consumer applications.

Previous efforts to develop lithium niobate modulators have been largely focused on the traditional telecommunication wavelengths within the infrared light spectrum. However, working at shorter visible wavelengths can significantly reduce the size of the device as well as the power consumption. In addition, such modulators would also be eligible for 'Visible Light Communication (VLC)', which has recently attracted a lot of interest.

As Fukuzawa explains, 'All the basic visible colours – red, green, and blue laser lights were successfully modulated by our optical modulator for the first time. In contrast, 5G optical communication uses infrared laser light with a much longer wavelength than visible light. Since the required energy (voltage) for optical modulation is proportional to wavelength, shorter wavelengths of visible laser light can significantly reduce energy for data transfer and can therefore contribute to sustainable solutions for data communication. Since the energy consumption of data communications is so significant, the benefit of adopting visible light for data communications plays an important role.'

> **Lithium niobate has proved difficult to work with – resulting in lithium niobate modulators that are clunky and expensive.**

Importantly, this work shows for the first time that all the basic visible light – red, green, and blue – can be successfully modulated by lithium niobate modulator. This has not been reported previously, even using bulk lithium niobate instead of sputtered film. This work has significant applications since lithium niobate has great potential for imaging applications. It also has the advantage of lower costs for the consumer.

Until now, visible light communication has not been realised. As Fukuzawa summarises, 'Now that we have demonstrated visible light modulation in devices, fast data speed for consumer applications has great potential. Our optical modulator using sputtered thin film lithium niobate is low cost, and using visible laser light results in a significant reduction in energy. This development opens up an exciting opportunity for making ultrafast data transfer a reality.'

In further tests, the researchers measured the relevant figure of merit for device size and power consumption, revealing that it did scale with the operating wavelength as expected. The TDK Corporation researchers conclude that lithium niobate modulators can be adopted for emerging consumer applications for any applications using visible light with very fast speed.

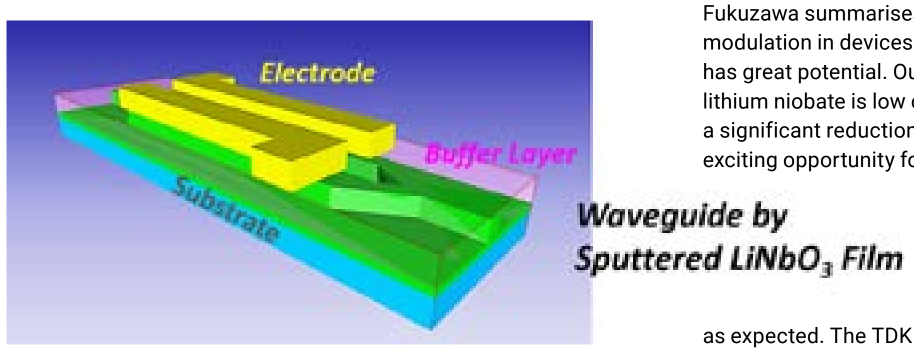


Figure 1. Schematic representation of visible light modulator using lithium niobate waveguide.

Personal response

What excites you most about this development?

When we first observed all the red, green, and blue (RGB) light modulations, we were very excited about it. No one had ever realised all the basic three RGB visible lights modulation by any optical modulators previously. We knew that we had found a way to obtain fast speed through visible light modulation.

How will people most notice the benefit of optical modulators being cheaper to produce in their everyday lives?

Consumers will benefit from this research in many ways, through any gadget or device that requires fast-speed RGB modulations. For example, at present it takes time to transfer data for large files. Waiting for such files to transfer will become a thing of the past!

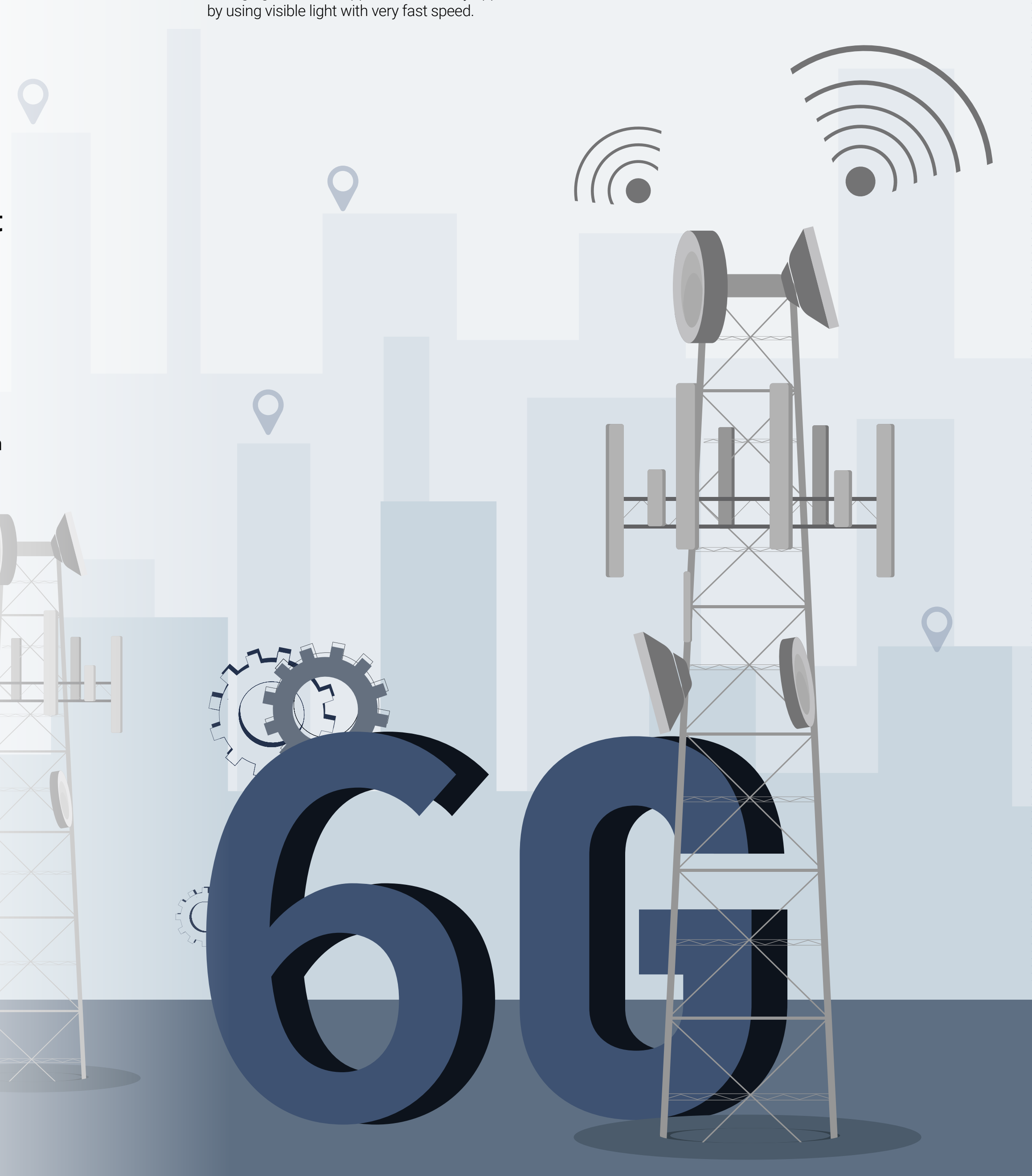
What are the main remaining challenges for ultrafast data transfer and communication?

Receiver technology with very fast speed must also be developed.

What will you be working on next?

The improved quality of lithium niobate sputtered film can further enhance the performance. This is the next focus for our work.

Lithium niobate modulators can be adopted for emerging consumer applications for any applications by using visible light with very fast speed.



Details

Hideaki Fukuzawa **Takashi Kikukawa**

e: hideaki.fukuzawa@tdk.com
e: takashi.kikukawa@tdk.com

Bio

Dr Hideaki Fukuzawa is a Senior Manager at TDK Corporation, responsible for optical devices for AR/VR glasses and beyond 5G optical communications.

Mr Takashi Kikukawa is a TDK Corporation Manager responsible for lithium niobate devices.

Further reading

Ozyurt, AB, et al, (2023) Energy and spectral efficiency of multi-tier LiFi networks. *IEEE Wireless Communications and Networking Conference (WCNC)*, 1–6.

Fukuzawa, H, et al, (2022) Visible light modulator by sputter-deposited lithium niobate. *AIP Advances*, 12(6), 065029.

Lee, C, et al, (2020) Advanced LiFi technology: Laser light. *Proc SPIE 11302, Light-Emitting Devices, Materials, and Applications XXIV*, 1130213.

Chi, N, et al, (2020) Visible light communication in 6G: Advances, challenges, and prospects. *IEEE Vehicular Technology Magazine*, 15(4), 93–102.

Wang, C, Zhang, M, Chen, X, (2018) Integrated lithium niobate electro-optic modulators operating at CMOS-compatible voltages. *Nature*, 562, 101–104.

TDK