## [8 minute read] In part 1 of this article, we explained how we use silicon photonics to control and modulate light with the aim of creating an optical field that contains data we want to process.

The MFT System Part 2: Free Space Optics

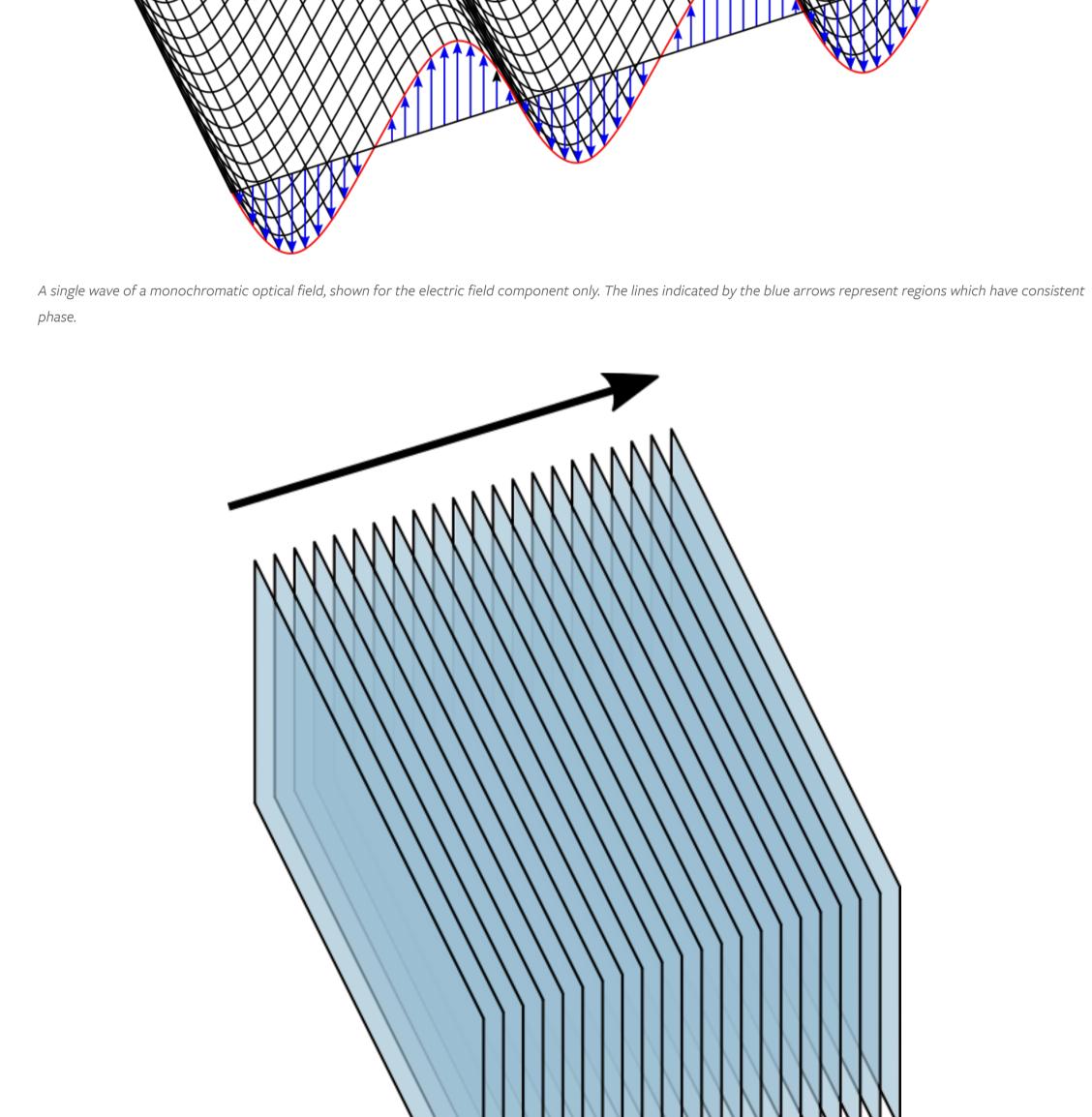
The Optalysys approach is very different to the other silicon photonic computing systems which are under development. Like our own designs, these systems use arrays of Mach Zehnder interferometers (MZIs) embedded in silicon to control light and perform multiplications. However, these other optical computing systems are only designed to perform multiplications for the Multiply and Accumulate (MAC) operations that are part of executing many deep learning models.

They use many more MZIs to create what is called a "systolic array", a cascade of processing nodes which perform calculations on information received from nodes further upstream in the data flow. In these models, light never leaves the silicon photonic system. Optalysys are different; we use silicon photonics to prepare a 2-dimensional field of optical information for nearly instantaneous parallel processing. Light must leave our silicon system so that it can perform a calculation through diffraction. This approach is unique even by the standards of photonic computing, and has some crucial advantages.

Not only can our system be used to efficiently calculate the Fourier transform of an array of data, but it can also be used to perform the same MAC operations that other silicon photonic systems are designed to execute with no additional overhead compared to the systolic array method. We'll come back to how we can perform general matrix processing tasks using Fourier optics in a later article; for now, we'll focus on how we make the transition from the silicon photonic stage to the free space processing environment.

Fourier Optics In explaining how this stage of our system works, it's helpful to describe some of the basic ideas behind the way in which light travels in free space. Light is a form of electromagnetic radiation, which travels as a wave. Because electric fields and magnetic fields are linked, this takes the form of two waves, representing the electric and magnetic fields, which oscillate at right angles to one another.

## The electrical (red wave) and magnetic (blue wave) fields of a photon oscillate in planes which are at right angles to one another; both are at a right angle to the direction in which the photon is travelling. For a source of light of constant phase and frequency, the kind emitted by a laser, we can represent the optical field in free space as a continuous wave:



way in which we can construct a mathematical function by superimposing simple harmonic functions.

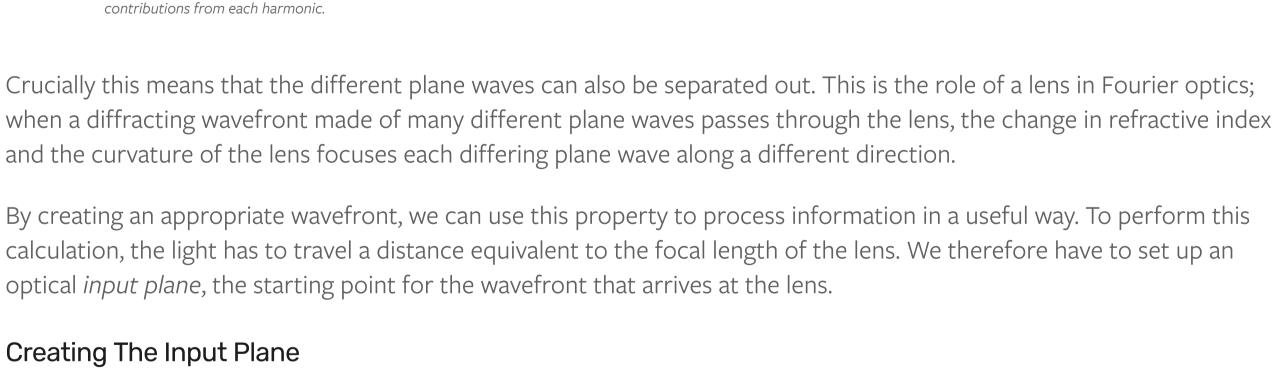
Over a volume of space that contains an optical field, these lines of constant phase collectively describe a

This is only true when light is travelling in free space, where it can spread out and form a plane wave. In a waveguide or

Fourier optics treats the optical field as being a linear superposition of many different plane waves. This is identical to the

series of flat planes.

fibre-optic cable, there are boundaries which prevent this spreading.



In our last article, we described how we use a silicon photonic chip to perform the following tasks:

1. Split a single source of laser light into many individual beams

that we want to transform.

section.

couplers.

to

strikes the lens.

**Prisms** 

line.

**Grating couplers** 

A superposition of harmonic functions to create a new function. The Fourier transform reverses this process, allowing us to isolate the individual

2. Encode complex values into the phase and amplitude of each beam by using Mach-Zehnder interferometers 3. Perform an additional stage of optical multiplication on each beam if required. We now want to emit that light into free space, creating an optical field which contains a representation of all the data

Once the silicon photonic system has performed the above steps, the processed light is then carried by waveguides to a 2-

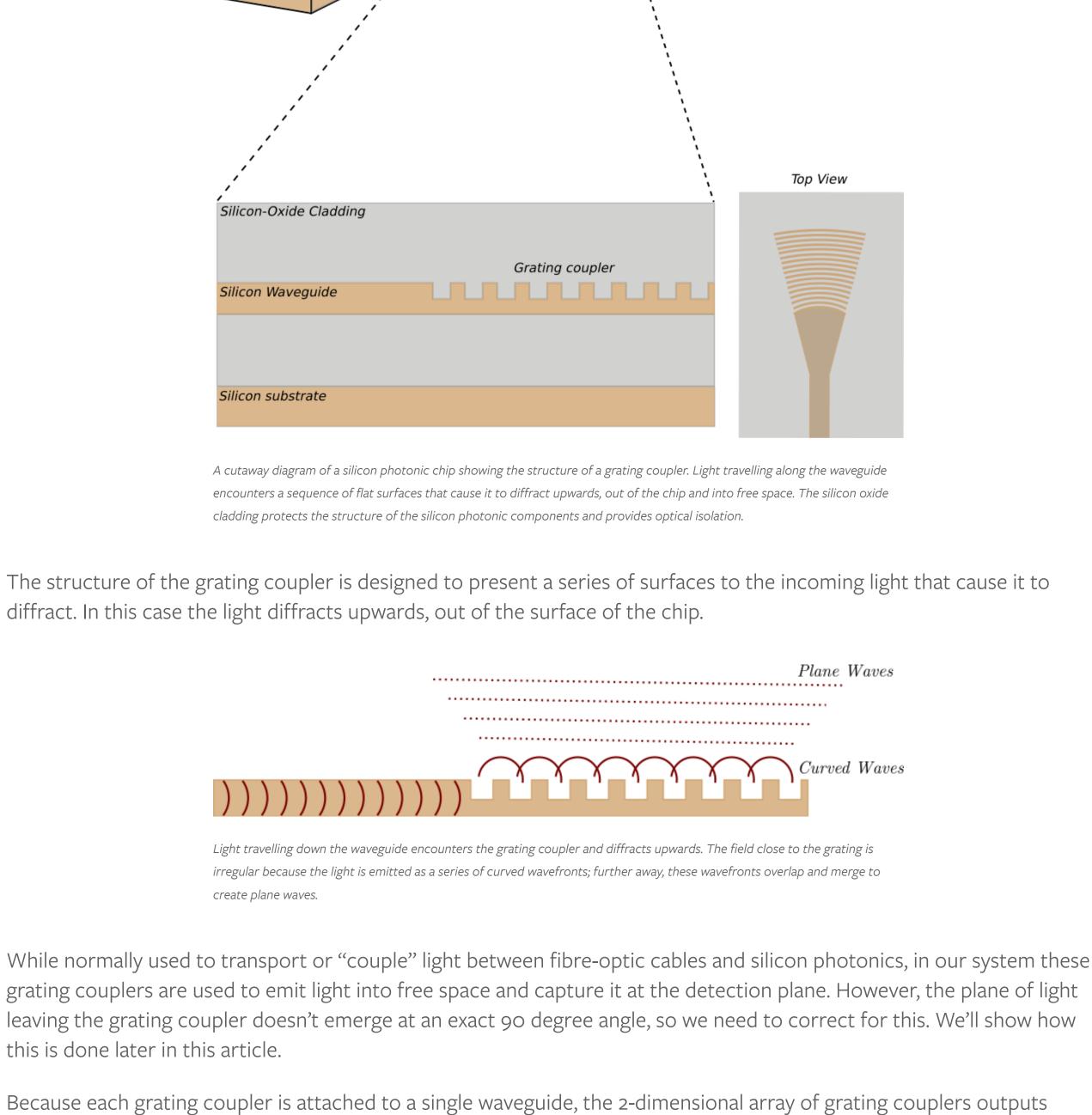
dimensional array of grating couplers where it leaves the silicon photonic system. We left a detailed description of how

grating couplers work for this article, as the way in which these components work influences the design of the free space

Waveguides to other

grating couplers

A grating coupler is a structure cut into a waveguide that uses diffraction to change the direction in which light is travelling. If you were to cut through our silicon photonic chip to show the structure of a grating coupler from the side, it would look something like this:



Micro-Lens array A micro-lens array is a flat grid of tiny lenses held in place by a supporting material.

individual points of light, each of which can be encoded with a different optical phase and amplitude. The number of

at a defined resolution (e.g 1920x1080). Our prototype device has a resolution of 5x5, provided by 25 individual grating

We can perform a Fourier transform using light emitted directly from the grating couplers, but this presents two

optical signal and causing additional interference where it isn't wanted.

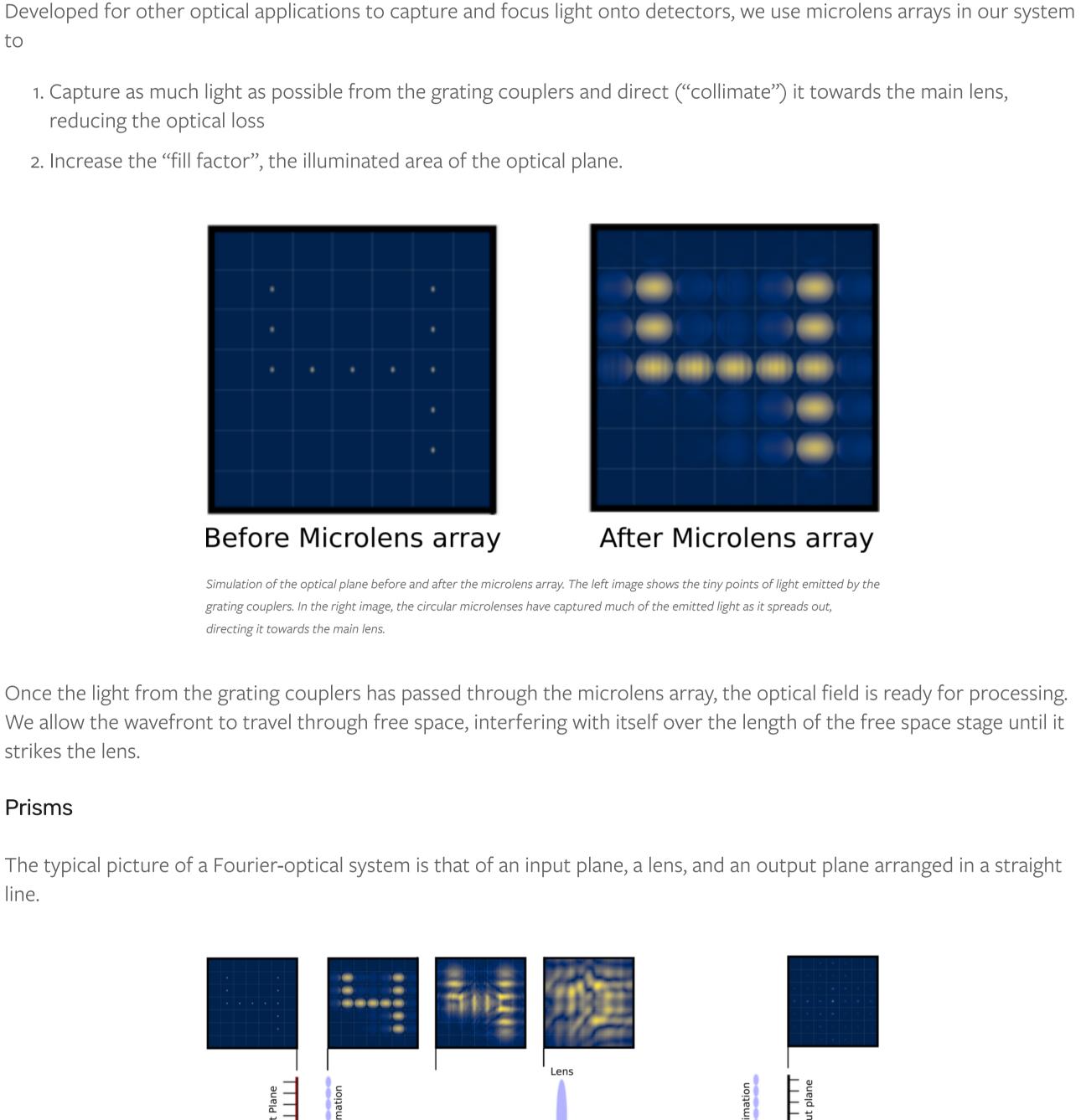
To address these problems, we need another component. Enter the micro-lens array.

points of light is a measure of the "resolution" of the system in much the same way that a television or monitor has pixels

problems. The first is that the size of the individual grating couplers (relative to the total surface area of the array) is very

small. The second is that the light leaving the grating couplers spreads out immediately, weakening the strength of the

A microlens array, a grid of miniature lenses designed to collect and focus light from tiny optical sources



adjusting the angle of the reflective surface, it allows us to correct the angle of the optical field from the grating couplers.

The complete free-space stage, the heart of our optical Fourier transform technology, shown splitting an optical signal into component plane waves. All the components

Now the wavefront is travelling in the correct direction, directed towards the main lens in the system. As it passes through

Now the wavefront is travelling in the correct direction, directed towards the main lens in the system. As it passes through

the lens, the superimposed plane waves that make up the field are separated and focused along different spatial paths,

A free-space optical system for performing the Fourier transform, with simulated images of the 2D electric field component of

We've used this image ourselves when explaining the idea behind our own system, but in reality this presents a problem

We've used this image ourselves when explaining the idea behind our own system, but in reality this presents a problem

Prisms provide a solution to this problem. Placing a prism over the micro lens array presents a reflective surface to the

can also insert a lens into the middle of the prism, so the free-space optics can be a single block of components.

This lets us use the optics in a much more compact configuration, but it also has an additional useful property; by

light that allows it to make another 90 degree turn, such that the beam now travels parallel to the surface of the chip. We

when it comes to making the system compact. As the array of grating couplers lies on the surface of the optical chip, this

design would mean that the entire free space section would have to point straight up, at a right angle to the surface of the

the optical field as it passes through space.

chip! To make matters worse, the detection array would need to be a separate component.

shown here are passive; they consume no power, but are capable of processing information at an almost arbitrary rate.

producing the pattern of bright spots that correspond to the 2-dimensional Fourier transform.

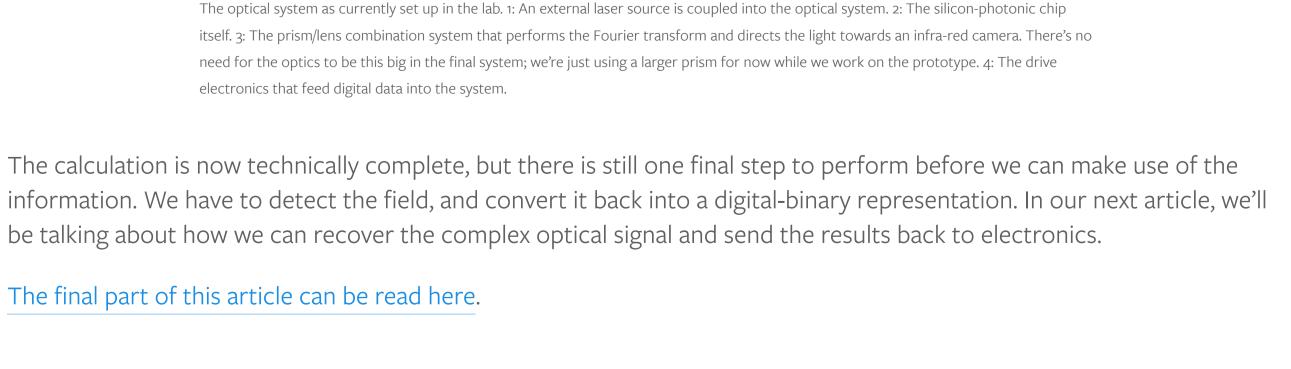
system prototype in our lab.

couplers which return the light back into silicon photonics.

A second microlens array is used to capture as much of this optical field as possible and focus it onto an array of grating

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A concept illustration of the system processing data. The input and output images are from real operations performed on the



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