



An Overview of  
**GPU** Accelerated  
**Crosslight FDTD**

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**Crosslight Software Inc.**

# Performance Acceleration Methods Implemented in Crosslight **FDTD** (**CLFDTD**)

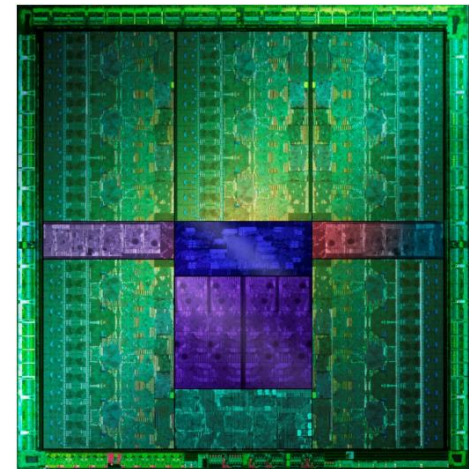
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## ■ MPI parallelization

- Multi-cores and multi-CPU's
- PC cluster

## ■ GPU acceleration

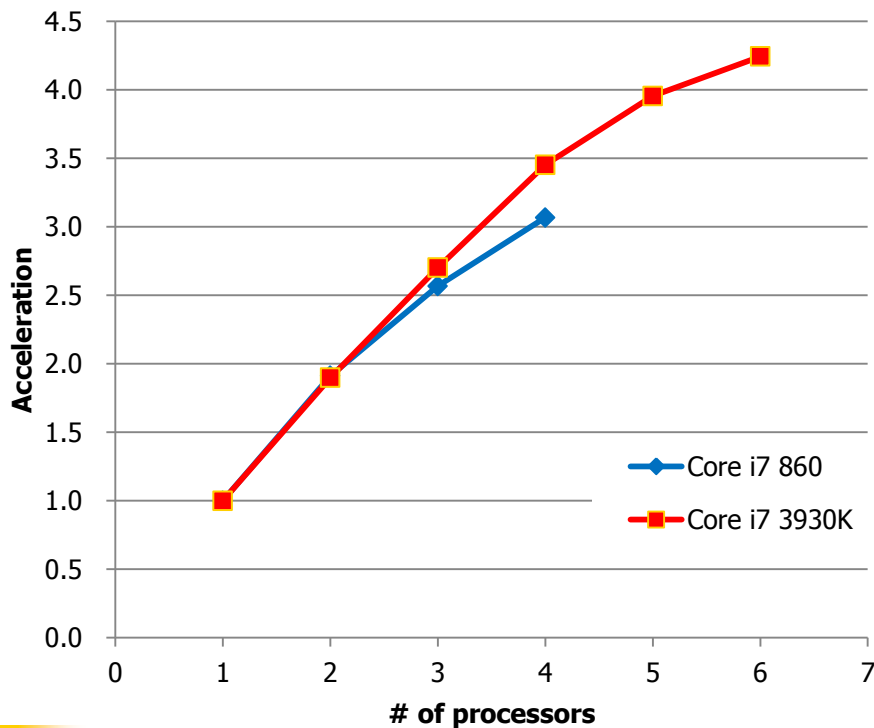
- Highly optimized for Nvidia's latest GPU architectures (Fermi and Kepler)
- Developed on CUDA environment



Nvidia Kepler GK110

# MPI Parallel Efficiency of Multi-core CPU

Comparison of Parallel Efficiency Between Two Different Generation of Core i7



Parallel efficiency of multi-core CPU is bounded by memory bandwidth ( $\sim 51\text{GB/s}$ ) when handling bandwidth limited application such as **FDTD**.

# GPU Card Used in Our GPU Benchmark

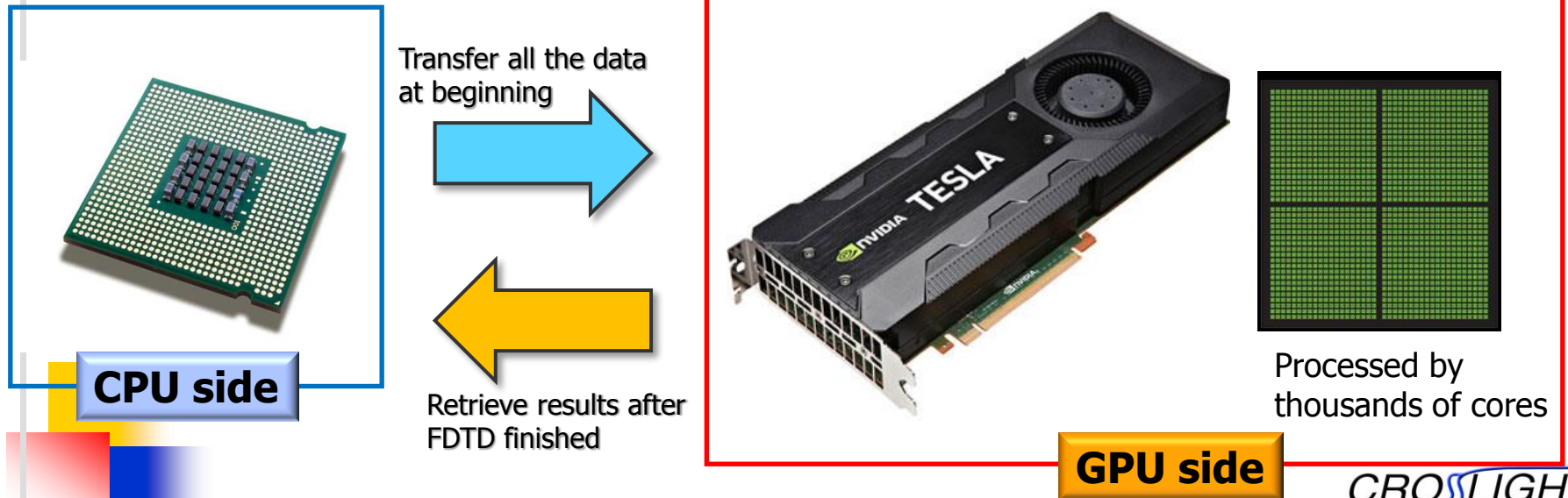
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|                  |                |
|------------------|----------------|
| Manufacture      | Nvidia         |
| Model            | GeForce GTX670 |
| Architecture     | GK104 (Kepler) |
| Memory           | 4GB GDDR5      |
| Memory Bandwidth | 192 (GB/sec.)  |
| FLOPS            | 2.5 TFLOPS     |
| TDP              | 170 Watts      |
| Price            | 400 USD        |

# GPU Implementation

- Transfer all the data from CPU to GPU only at once at initialization step.
- Most of the FDTD routines are processed at GPU side so that data transfer between CPU and GPU through slow PCI-express bus is kept to a minimum.
- Tuning CUDA kernel for recent GPU architecture (Fermi and Kepler)



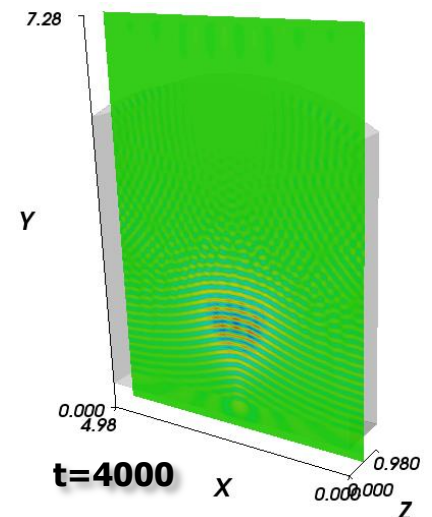
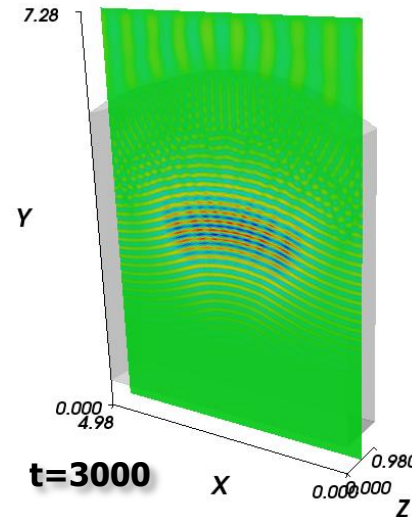
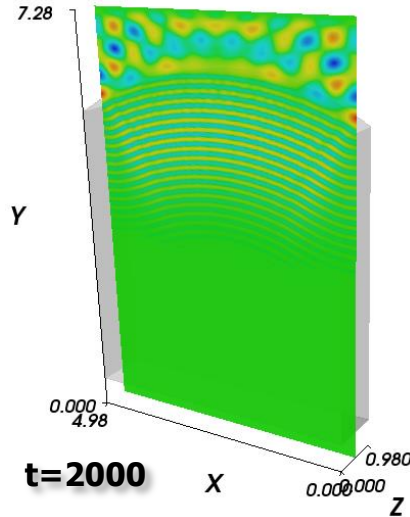
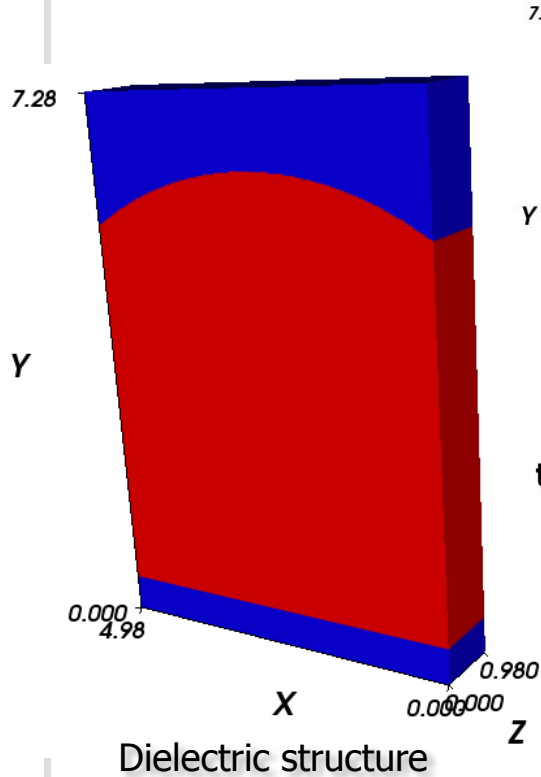


# Benchmark Tests of GPU Version of Crosslight **FDTD**

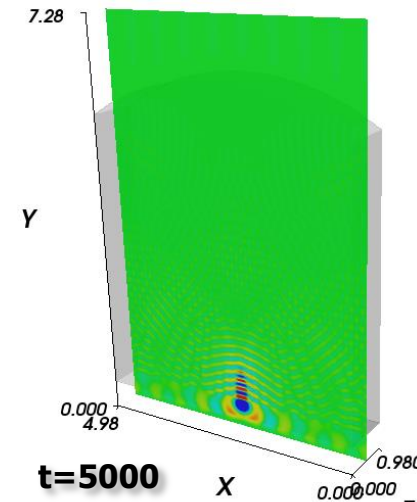
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- 3D Lens structure
- CIS3D CMOS image sensor

# 3D Lens Structure



Pictures show time evolution of  $E_z$ . Non-dispersive setting is used for the ease of seeing lens effect.

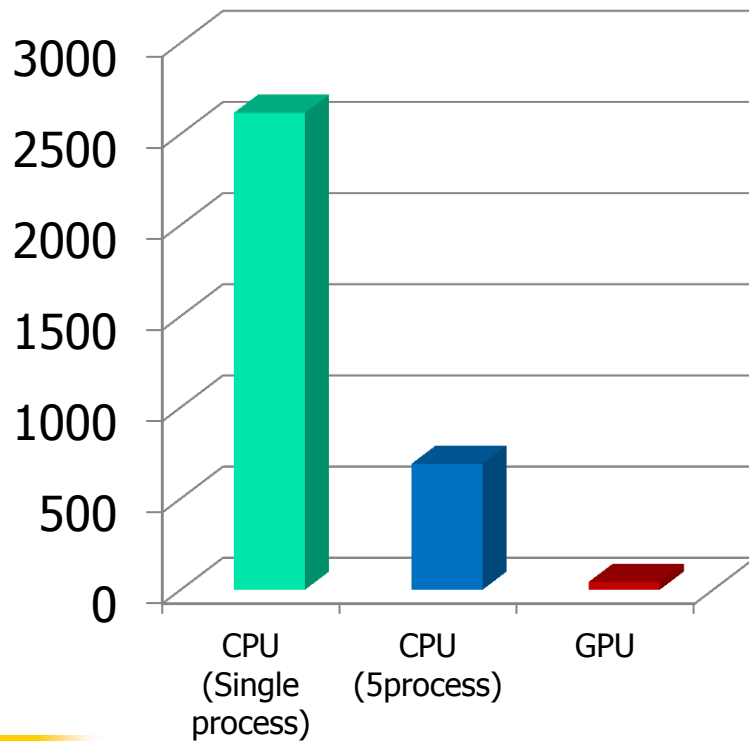


|                    |   |
|--------------------|---|
| FDTD grid size     | 250x365x50 = 4,562,500                  |
| Boundary condition | PBC on X and Z<br>CPML on Y (16 layers) |
| Material           | Silicon                                 |
|                    | 9-poles Lorentz dispersion              |
| Simulation steps   | 5000                                    |

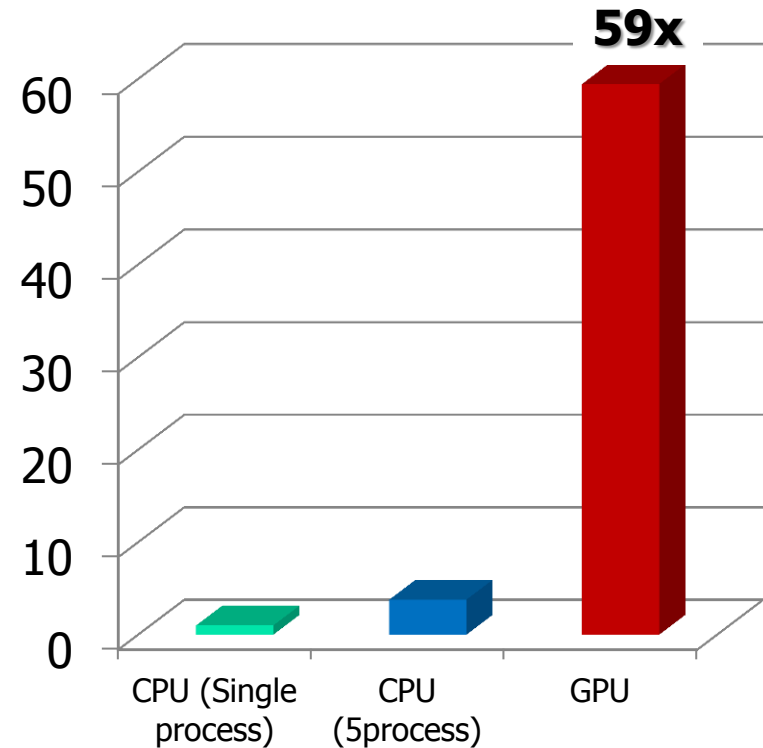
# Benchmark Results on 3D Lens FDTD Part I.

(Non-dispersive material case)

Simulation time (sec.)



Acceleration



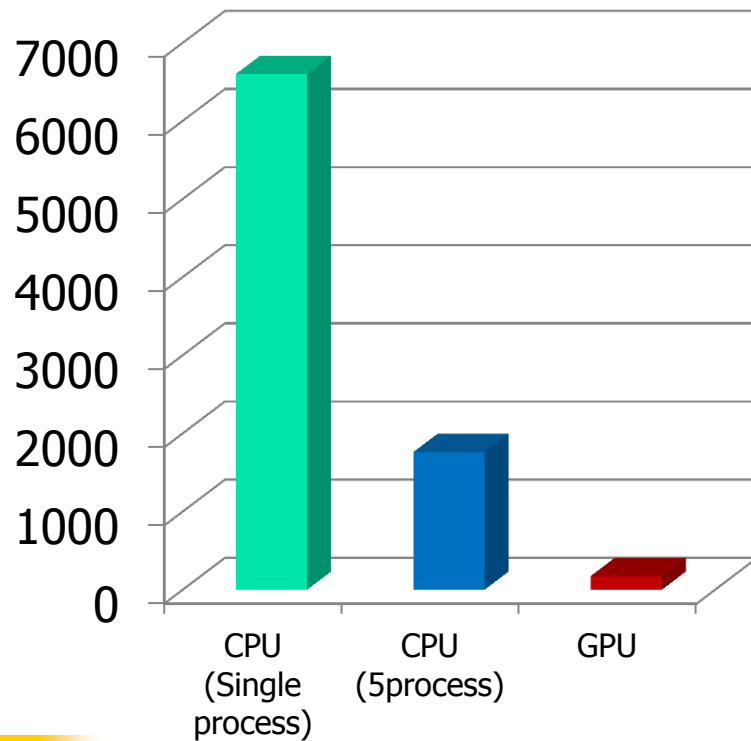
In non-dispersive material case,  
GTX670 is 59 times faster than  
single process of Core i7 3930K



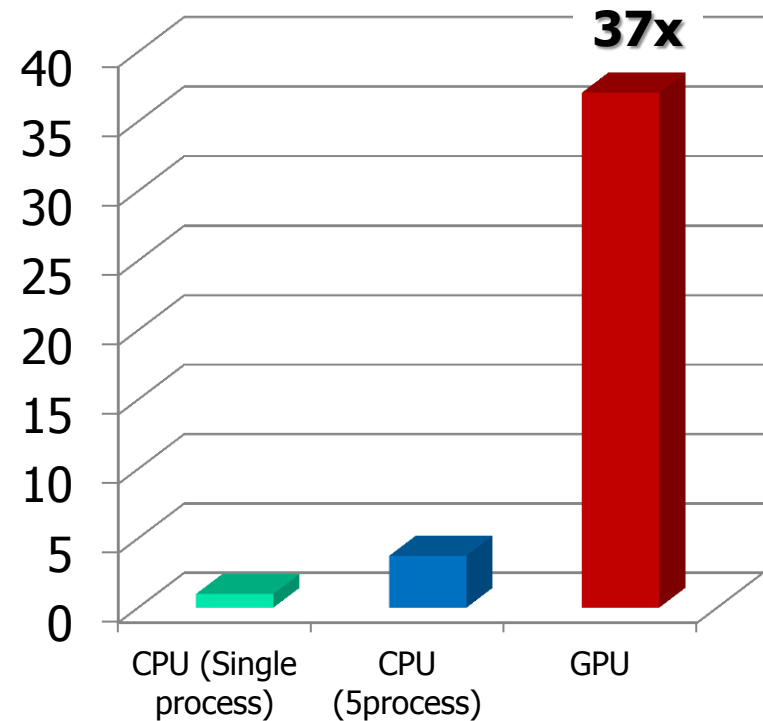
# Benchmark Results on 3D Lens FDTD Part II.

(Dispersive material case)

Simulation time (sec.)



Acceleration



In dispersive material case,  
GTX670 is 37 times faster than  
single process of Core i7 3930K

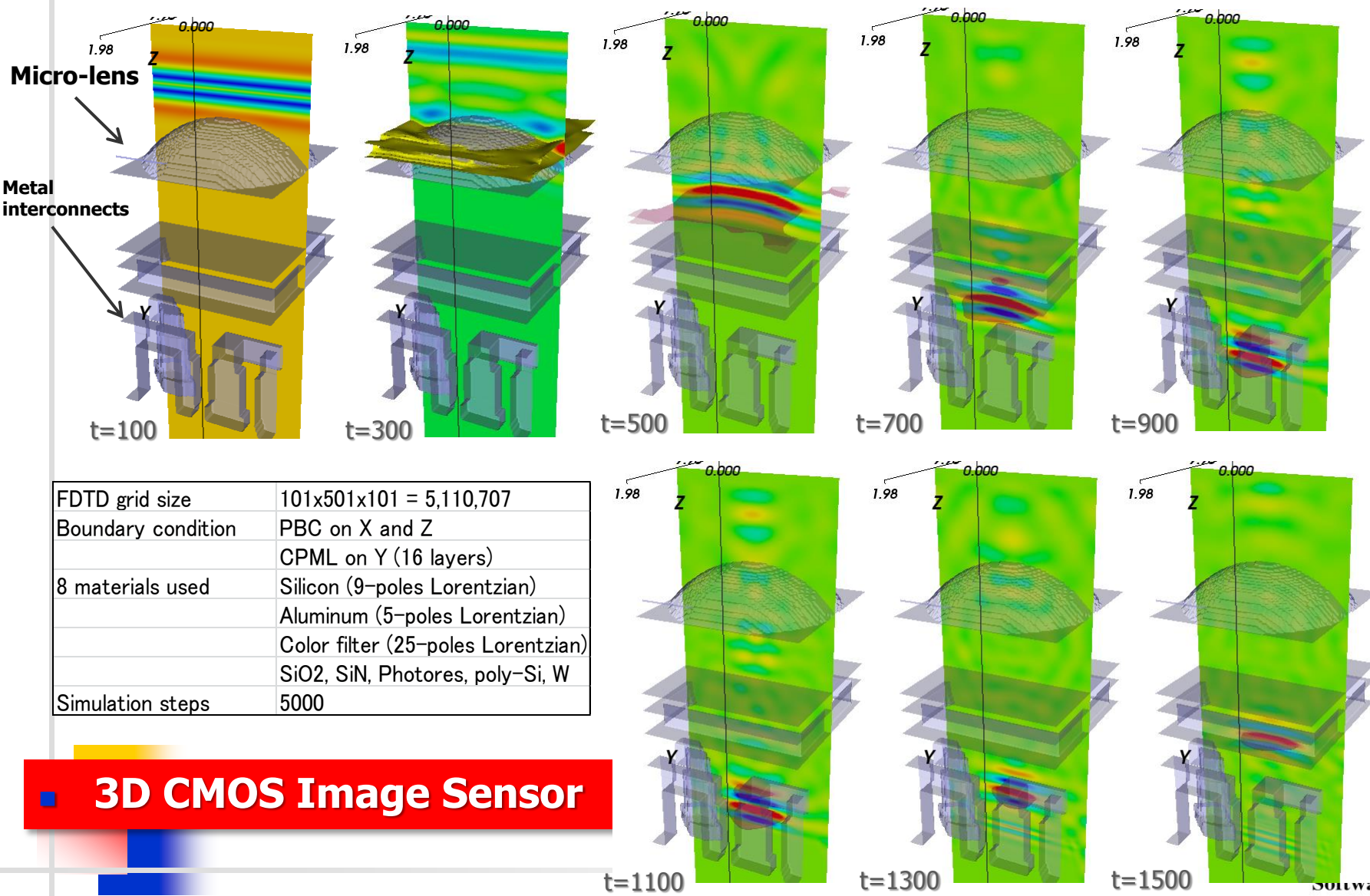


# Summary on 3D Lens FDTD Benchmark

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- Non-dispersive dielectric slab case marked 59x acceleration in compared to single process of Core i7 3930K.
- In dispersive case, i.e. material is represented by 9-poles Lorentz dispersion function, 37x acceleration is marked.

# CIS3D Structure



Micro-lens  
Metal interconnects

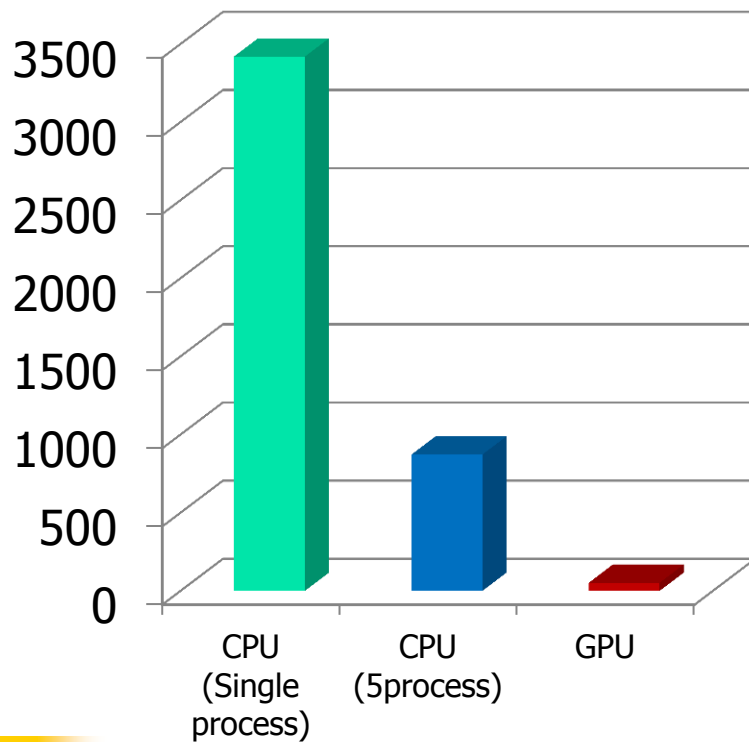
|                    |   |
|--------------------|---|
| FDTD grid size     | 101x501x101 = 5,110,707   |
| Boundary condition | PBC on X and Z<br>CPML on Y (16 layers)   |
| 8 materials used   | Silicon (9-poles Lorentzian)<br>Aluminum (5-poles Lorentzian)<br>Color filter (25-poles Lorentzian)<br>SiO <sub>2</sub> , SiN, Photores, poly-Si, W |
| Simulation steps   | 5000  |

**3D CMOS Image Sensor**

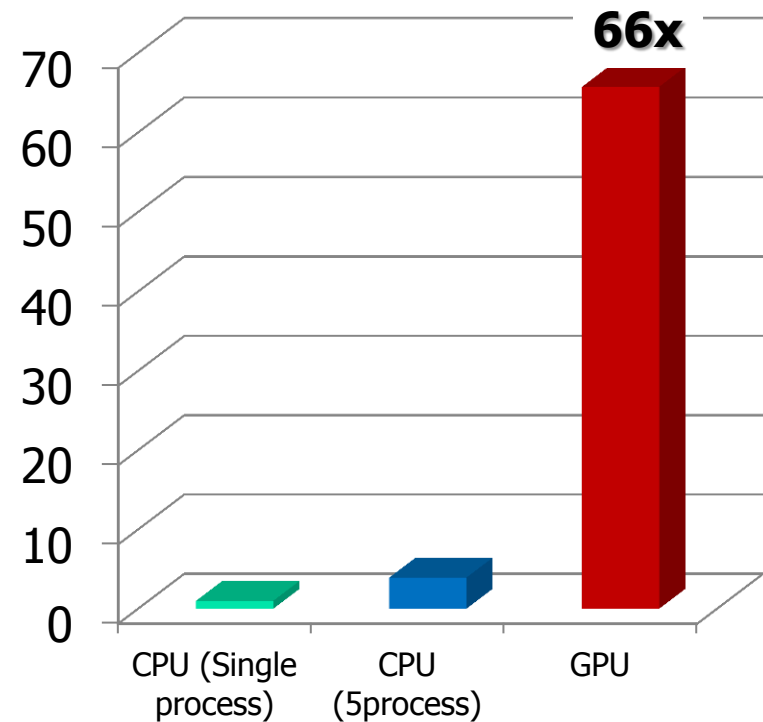
# Benchmark Results on CIS3D FDTD Part I.

(Non-dispersive material case)

### Simulation time (sec.)



### Acceleration

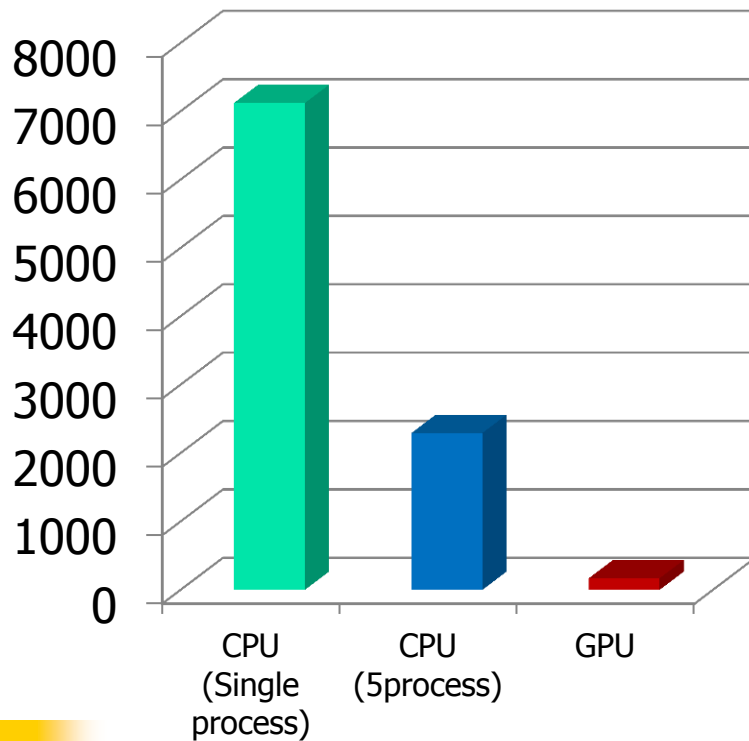


In non-dispersive material case,  
GTX670 is 66 times faster than  
single process of Core i7 3930K

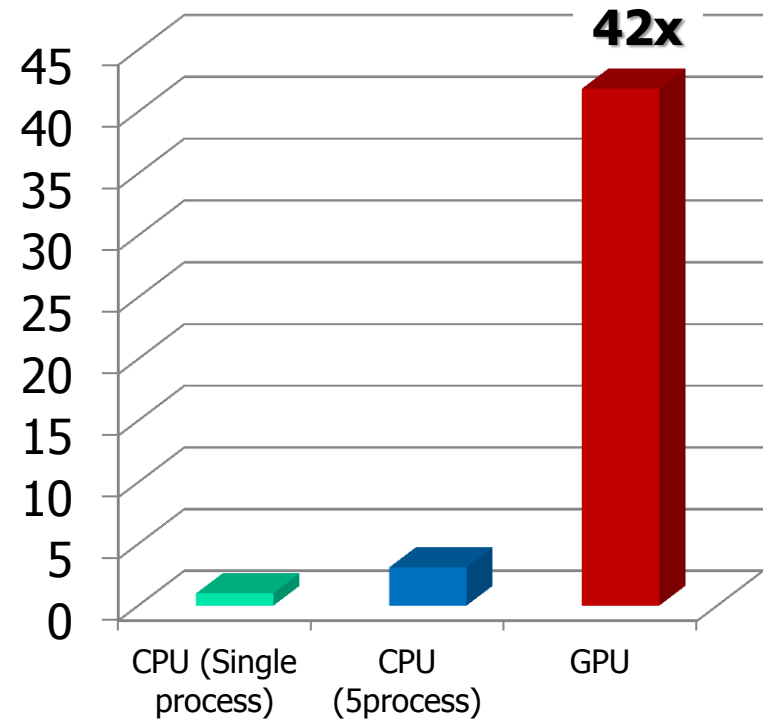
# Benchmark Results on CIS3D FDTD Part II.

(Dispersive material case)

Simulation time (sec.)



Acceleration



In dispersive material case,  
GTX670 is 42 times faster than  
single process of Core i7 3930K



# Summary on CIS3D FDTD Benchmark

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- Non-dispersive case marked 66x acceleration in compared to single process of Core i7 3930K.
- 42x acceleration is marked for dispersive case.
- GPU acceleration is even better than that of simple 3D lens structure.



# Summary

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- GPU version of Crosslight FDTD achieved 66x GPU acceleration for 3D realistic device structure.
- Our benchmark results show that cheap GPU card now offers computation speed comparable to a cluster of 10 Core i7 3930K PCs, which corresponds to 60 cores.