

Parallel Fabrication of Three-dimensional Nanostructures Utilizing Two-Photon Polymerization and Electroless Plating

T. Barth, T. Tanaka, N. Takeyasu, and S. Kawata

Nanophotonics Laboratory, RIKEN (The Institute of Physical and Chemical Research), Wako, Saitama, Japan

Photopolymerization technologies for creating microstructures are usually not suitable for the fabrication of nanostructures because, being an optical technology, feature size is limited to the wavelength of light. A process known as Two-Photon Polymerization (TPP), using polymers that require two photons rather than one photon to polymerize, allows us to create complex three-dimensional resin structures with features on the scale of 100nm, since absorption of the light occurs only at the focal region of a tightly focused beam via a non-linear multiphoton process. Done serially, this process is slow in producing multiple structures. Creating meta-materials, materials with properties originating from both their chemical and structural makeup, would require a vastly more productive method. As a step towards this, we utilized thousands of tiny lenses (a microlens array or MLA) to allow the fabrication of periodic structures in parallel, resulting in production yields two orders of magnitude higher than single-beam TPP. The resulting structures, however, are composed only of resin, which is not suitable for many applications. By utilizing electroless plating of silver particles onto the surface of the resin, three-dimensional conductive nanostructures are realized. The electroless plating requires very small particles of silver for proper coating, because large particles do not evenly coat the structure surface and inhibit conductivity. My direct research involved changing the electroless plating parameters to achieve finer particles for even coating of complex structures.

Impetus

We want top-down fabrication techniques for producing arbitrary three-dimensional nanostructures.

Method

- ✓ Photopolymers are materials that harden (polymerize) upon exposure to UV light
- ✓ Using a focused laser, we can selectively solidify a structure
- ✓ Afterwards, we wash away the unpolymerized resin
- ✓ Resulting structure is non-conductive, to make conductive we use an electroless plating process
- ✓ Specialty polymers optimized for electroless plating or for biocompatibility are possible, expanding applications

What about the Diffraction Limit?

- ✓ Normally feature size is limited by the diffraction of light, the smallest focal area is almost the same as the wavelength
- ✓ By utilizing non-linear properties of two-photon absorption, polymerization occurs only at the focal point in an area smaller than the diffraction limit
- ✓ This allows features smaller than 120 nm

What is Parallel?

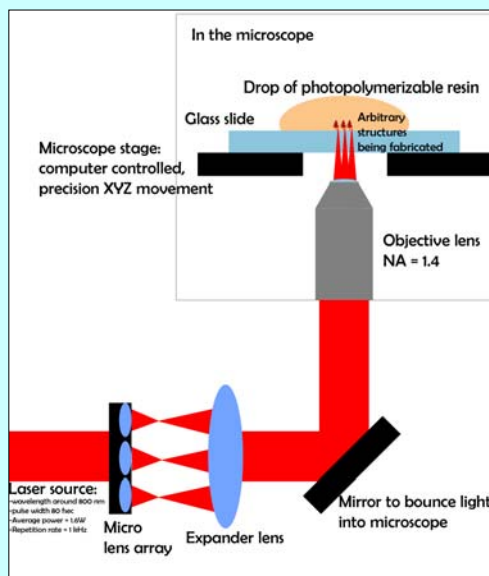
- ✓ For thousands of structures, fabricating one by one takes too long
- ✓ Solution: Split the laser beam into many beams using an array of tiny lenses (a microlens array or MLA)
- ✓ Each beam has its own focal point, so the process works the same, except now with many simultaneous fabrication points

Process

✓ The fabrication is done using an optics table to prepare the beam and a microscope with a computer controlled stage to perform the fabrication.

✓ Steps of process:

1. Place drop of photopolymer on a glass slide
2. Pulse laser to control polymerization
3. Use mechanical stage to move focal points in xyz-axes to “draw” arbitrary three dimensional structures



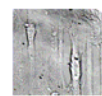
Diagram

4. Wash away photopolymer, leaving behind only polymerized parts
5. Immerse resulting resin structure in an electroless plating solution to coat it with silver particles

Applications

✓ **Without Plating:**

- a. **Biology:** for example, creating scaffolding for growing cells
- b. **Mechanical components:** proof of concept = a resin spring that follows Hooke's law



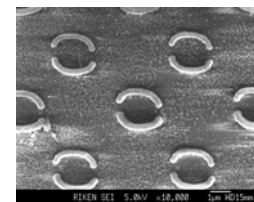
Cardiomyocytes growing on a polymerized scaffold (scale 10 μm)



Mechanical spring with attached resin ball (scale 2 μm)

✓ **With Plating:**

- a. Now we can create periodic, conductive nanostructures
- b. With conductivity, can build nanoscale electromagnetically resonating structures for use in meta-materials



Array of nanoscale, conductive split rings. Potential for use as resonators

Conclusions

With the addition of special resins for biology, the electroless plating process, and a microlens array, two photon polymerization is a flexible but powerful technique for nanoscale fabrication of structures.

Acknowledgements

My research in the electroless plating process was made possible by a grant from the National Science Foundation. The main nanofabrication research is funded by the RIKEN (The Institute of Physical and Chemical Research) Nanoscience and Technology Program and the Extreme Photonics Program.