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# Challenges in fabrication towards realization of practical metamaterials

Gwanho Yoon[1+], Inki Kim[1+] and Junsuk Rho[1,2*]

[1]Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, 790-784, Republic of Korea

[2]Department of Chemical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, 790-784, Republic of Korea

[*]Correspondence: jsrho@postech.ac.kr

[+]These authors contributed equally to this work.

**Abstract**

Metamaterials, artificially structured materials consisted of sub-wavelength unit cells, have attracted tremendous attentions in physics, material science, and engineering over the past decade. Many exotic and extraordinary electromagnetic phenomena such as negative refractive index, invisibility cloaking and super-resolution imaging have been realized through metamaterials. Now, metamaterials need to be focused on nanoscale optical metamaterials, operating at ultra-violet (UV), visible and near-infrared (NIR) frequencies for practical applications of them. Here, we review the fundamentals, recent progress, main challenges, and future direction of optical metamaterials and related fabrication processes. The fundamentals and recent progress of the optical metamaterials are discussed with representative examples such as negative index metamaterials and invisible cloaks. Main challenges in fabrication for practical metamaterials, three-dimensional and large-scale metamaterials, and brief discussion about the outlook for the next generation scalable nanofabrication methodologies are followed.

## 1. Introduction

In nature, the properties of materials are generally determined by their chemical composition and the bonding type. In human history, people have tried to make superior materials through various methods such as hardening, annealing, alloying, doping and so on. Metamaterials have been developed along with the same motivation. Metamaterials, artificially structured materials composed of sub-wavelength unit cells, have shown exotic and extraordinary electromagnetic phenomena, which cannot be explained with conventional optics and cannot be obtained in nature, such as negative refractive index **[**1-6**]**, invisibility cloaking **[**7-9**]**, super-lens and hyper-lens imaging beyond diffraction limit **[**10-15**]**, artificial chirality **[**16-17**]**, electromagnetically induced transparency **[**18**]** and perfect absorbers **[**19**]**. The naturally unattainable properties of metamaterials are determined not by the chemistry but by the physical structure of the artificial unit cells called meta-atoms. By changing the design of sub-wavelength meta-atoms, the electromagnetic properties (permittivity and permeability) of metamaterials can be tailored and manipulated. Depending on the size of the meta-atoms, the operating frequency region could be controlled and tuned for the different purposes. In early 2000s, to prove the