

## Effective Switching of Microwaves by Simple Water-Based Metasurfaces

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Extensive efforts in the field of metamaterials (MMs) and metasurfaces (MSs) have recently enabled remarkable physics and devices capable of addressing several important scientific and technological challenges (N. Zheludev and Y. S. Kivshar, *Nat. Mat.*, 11, 917-924, 2012; I. B. Vendik and O. G. Vendik, *Techn. Phys.*, 58, 1-24, 2013; C. L. Holloway et al., *IEEE Ant. Propagat. Mag.*, 54, 10-35, 2012; H.-T. Chen, A. J. Taylor, and N. Yu, *Rep. Prog. Phys.*, 076401, 2016). Due to small material losses, attention was particularly devoted to all-dielectric relativizations of MMs and MSs (S. Jahani and J. Zubin, *Nat. Nanotechn.*, 11, 23-36, 2016). The profound properties of all-dielectric MMs and MSs are due to high-permittivity inclusions of appropriate shape situated in a low dielectric matrix. At microwave frequencies, usually barium strontium titanate was used to form the required inclusions. This ceramic material is rather costly, hard to form, and has limited dynamic properties. Massive practical applications require, however, simple and cheap solutions with highly tunable dynamic properties. To this end, pure water was recently proposed for the consideration in MM and MS design due to its low price, abundance, bio-friendly nature and highly tunable properties. Interesting mechanically and/or thermally tunable water-based MS designs were demonstrated (A. Andryieuski et al., *Sci. Rep.* 5, 13535, 2015; M. Odit et al., *Appl. Phys. Lett.* 109, 011901, 2016), and almost perfect water-based absorbers were reported (Y. J. Yoo et al., *Sci. Rep.* 5, 14018, 2015; Q. Song et al., *Adv. Opt. Mat.* 5, 1601103, 2017). While these pioneering research efforts are significant, they mostly utilize inclusions which are not easy to make. In this work we build upon these initial efforts and present numerical (Comsol Multiphysics) and experimental (rectangular waveguide) results for a variety of microwave MSs based on very simple and easily made “rod-like” water elements in a dielectric Rohacell 51 HF matrix. An example of our results show how one orientation of the MS (vertical inclusions, Fig. 1, top-left) has a low transmittance,  $T$ , and thus blocks the incident waves (Fig. 1, middle), while its mechanical rotation by  $90^\circ$  (horizontal inclusions, Fig. 1, bottom-left) enhances the transmission and lowers the reflection,  $R$  (Fig. 1, right). In the presentation, we will also show how this behavior can be enhanced by stacking these MSs in free space, for which effective switching (on and off) of the waves emitted by a nearby dipole antenna is reported. We believe that the proposed water-based MSs may serve as easy-to-use, portable microwave sensors for quick and cheap identification and characterization of biological and chemical particles, and water micro-plastic contaminants.

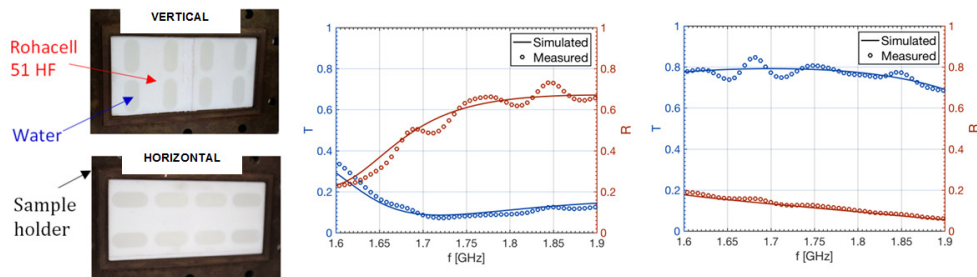


Figure 1. Designed MSs (a). Transmission ( $T$ ) and reflection ( $R$ ) spectra for vertical (b) and horizontal (c) MSs.