

## Application Note AN M116

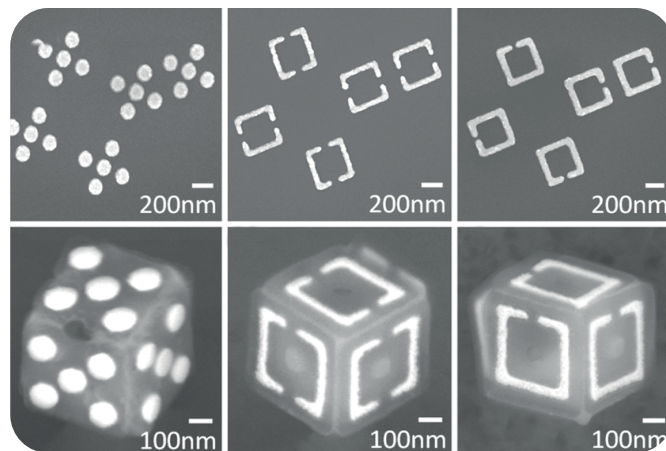
# Bruker FTIR takes Part in the Revolution of Meta-Material

### Introduction

WIKIPEDIA dictionary defined the so-called meta-materials as artificial materials engineered to have properties that may not be found in nature. They are assemblies of multiple individual elements fashioned from conventional microscopic materials such as metals or plastics, but usually arranged in pre-designed periodic patterns. During the last two decades, many scientists in different fields have donated a lot of effort to tailor the novel properties of meta-materials, in particular the optical ones. For example, the development of photonic crystals has given us an unprecedented flexibility in designing both linear and nonlinear optical properties, in terms of refractive index and dielectric permittivity, as a function of wavelength, and for different directions and polarizations. [Ref.1]

### Experiment

As a pioneer FTIR spectrometer manufacture offering peak performance, Bruker has witnessed these exciting revolutions of meta-material. For instance, in Ref.2, Prof. Giessen and his team had manufactured metallic split-ring-resonator (SRR) metamaterial nanoantennas using hole-mask colloidal nanolithography, and the resonance frequencies can be adjusted easily by changing SRR geometries. For each sample, the resonance frequency with its polarization dependence has been successfully measured using Bruker VERTEX 80 spectrometer attached with a Bruker HYPERION microscope. As examples shown in Fig.1(a)(b), the sample has clear enhancement in reflectance at 2800 nm



Keywords	Instrumentation and Software
FTIR	VERTEX series or INVENIO R
Meta-materials	Transmittance/Reflectance stages
Photonic band gap	Mapping evaluation
Broad range FTIR	HYPERION Microscope
Sub-wavelength structures	OPUS 3D software

( $3570\text{ cm}^{-1}$ ) for incident electric field polarized parallel to the ring gap, and  $1750\text{ nm}$  ( $5710\text{ cm}^{-1}$ ) for incident electric field polarized orthogonal to the ring gap, respectively. The agreement between experiment and numerical simulation is extraordinarily good.

Similarly, a novel SRRs arrangement in three dimensions has been introduced by Prof. Pol van Dorpe's team. [Ref.3] Various optical resonances from different faces on the 3D cube were confirmed by FTIR reflectance experiment on Bruker VERTEX 80v spectrometer with HYPERION microscope, as shown in Fig.2. This success of 3D SRR patterning opens a great probability of optical applications like biosensing, SERS, or isotropic negative-index metamaterials.

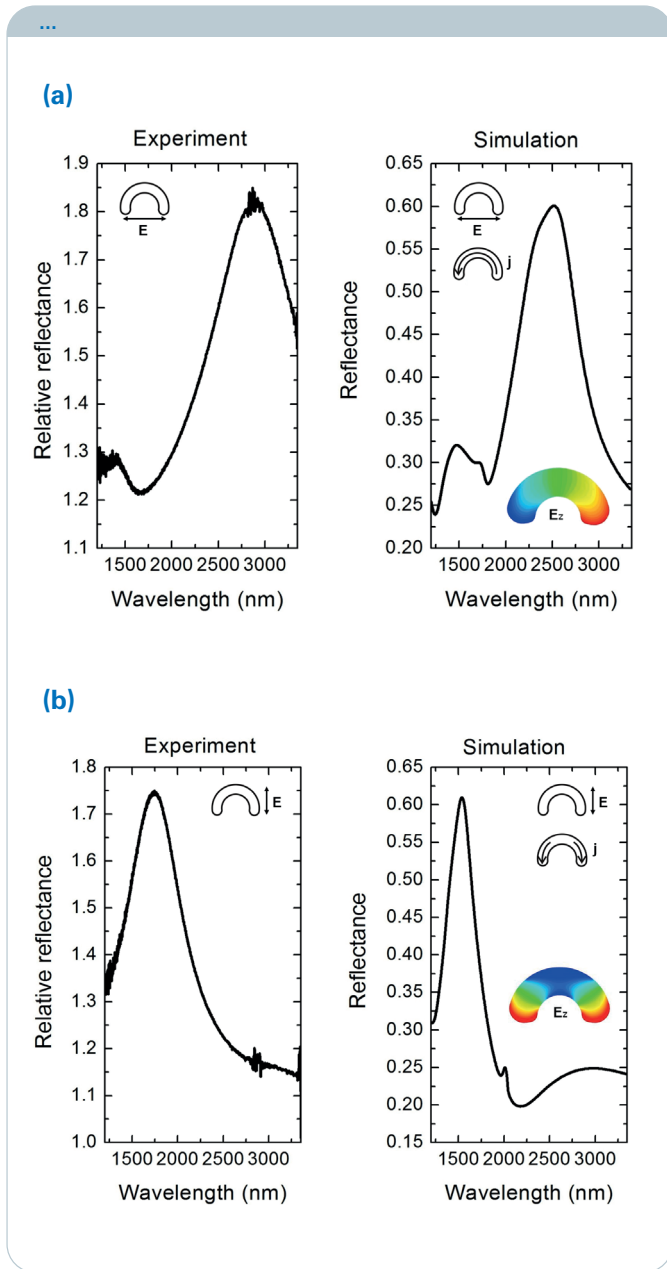


Fig.1: Experimental (FTIR) relative reflectance and numerically simulated reflectance on SRR sample for incident electric field polarized parallel (a), and orthogonal (b) to the ring gap. [Ref.2] Measured on Bruker VERTEX 80 with HYPERION microscope using reflectance mode.

### Spectrometer performance

The most specific feature of meta-material is the designable optical response at a certain frequency range. Different sub-wavelength structures produce various optical effects appearing at the range from several THz (far-infrared) to several eV (visible and UV). Therefore, a flexible spectrometer covering wide spectral range is very necessary for meta-material research.

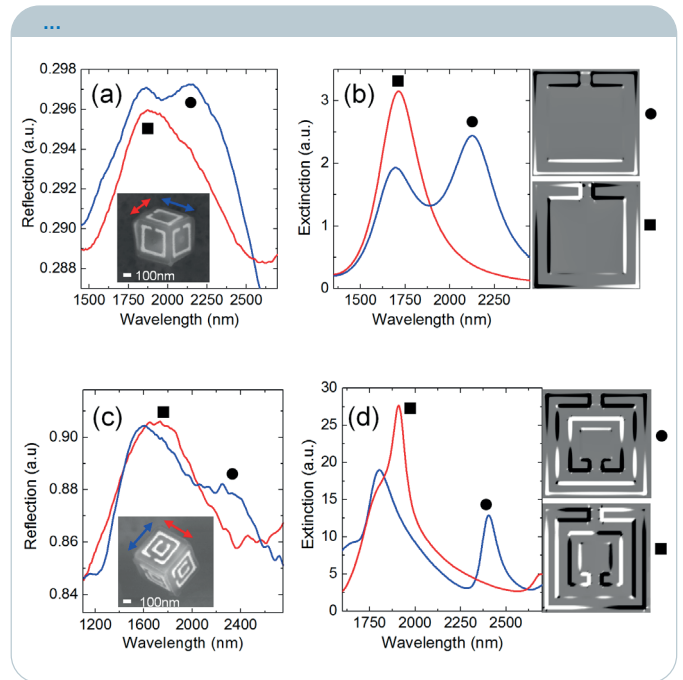


Fig.2: Experimental and simulated optical spectra of cubes with patterned (a,b) single and (c,d) double SRRs on all faces. (a) Single-particle Fourier-Transform (FT) IR reflection measurement of a six-faced cube decorated with single SRRs. Inset: SEM image of the measured cube. The arrows indicate the polarization of the incident light. (b) Corresponding simulated extinction spectra. Insets: charge density distribution of the indicated resonances. (c) Single-particle FTIR reflection measurement of a six-faced cube decorated with double SRRs. Inset: SEM image of the measured cube. The arrows indicate the polarization of the incident light. (d) Corresponding simulated extinction spectra. Insets: charge density distribution of the indicated resonances. [Ref.3] Measured on Bruker VERTEX 80v with HYPERION microscope using reflectance mode.

### a) Wide range extension

Bruker VERTEX series FTIR spectrometer, for instance VERTEX 80v, can optionally be equipped with optical components to cover the spectral range  $5\text{ cm}^{-1}$  in the very far IR, or terahertz region, through the mid IR, near IR, visible and ultraviolet spectral ranges all the way up to  $50,000\text{ cm}^{-1}$ . Automated switching in the full spectral range is provided by the four position automatized beamsplitter exchange unit BMS-c which works even under vacuum condition. In connection with an optional external detector chamber in total up to five detectors can be permanently mounted and remotely selected. All of these detectors are usable to acquire data of samples placed inside the standard sample compartment.

The next generation intuitive R&D FTIR spectrometer INVENIO R can be optionally equipped for the broad spectral range from  $15\text{ cm}^{-1}$  to  $28,000\text{ cm}^{-1}$ . Its high innovative MultiTec™ detector technology can bear up to 5 software

controlled room temperature detectors covering the entire achievable spectral range without manually changing detectors.

## b) Accessories

To fulfill the different measurement modes for meta-material, Bruker offers various transmission/reflection stages.

- A513: Bruker Optics reflection accessory, 13°-83°.
- 1004794 or 1021228: Accessory for reflectance measurements with perpendicular incidence.
- A510/Q-T: Reflection/Transmission accessory, angle of incidence 11° for spectrometers with QuickLock mount.
- A480 or A480/8: Parallel beam Transmittance accessory for the analysis of flat samples with high index of refraction (e. g. semiconductors).
- 10 Spec (1000390): Reflection unit "Pike 10Spec" with QL and Mask Set. Sample illumination using collimated beam precisely fixed at 10 degrees.

## c) HYPERION infrared microscope

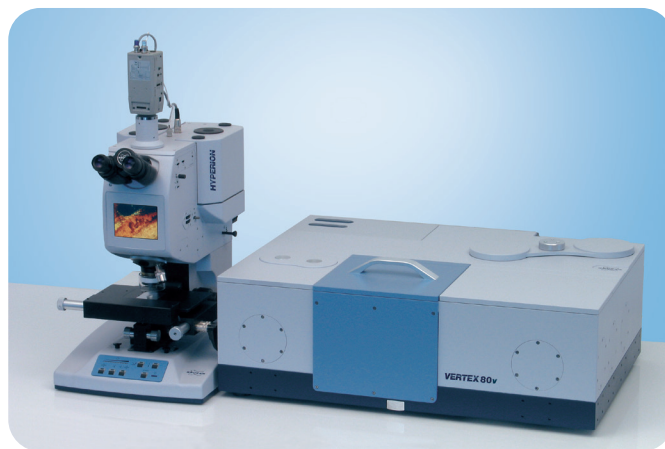
While the deposited meta-material samples are very small, or the homogeneity of the sample needs to be checked, Bruker INVENIO or VERTEX FTIR spectrometers can be attached with a Bruker HYPERION infrared microscope for further microscopic investigation.

The spectral range of the HYPERION can be extended from the middle infrared to the near infrared (NIR), even to the visible (VIS, up to 25,000 $\text{cm}^{-1}$ ) and down to the far infrared (FIR, down to ca. 50 $\text{cm}^{-1}$ ). To cover this extremely broad spectral range, many different detectors are available and can easily be exchanged by the user. The HYPERION can be equipped with up to two detectors in parallel, where the switching between positions is controlled by the software. If precise positioning or controllable temperature change is necessary, very accurate xyz stage and temperature (-196 to 600°C) controlled stages are available as an option (A699-T and A699-TR).

Some advanced property, like polarization dependent perfect absorption/reflectivity on meta-material devices can be chemically mapped as well under HYPERION 3000, which is equipped with focal-plane-array detector and polarizer-units. An area of up to 340\*340 $\mu\text{m}$  with 16384 spectral can be measured simultaneously, and the chemical mapping

## Typical configuration

- VERTEX80 + S125/8V (FTIR spectrometer with high resolution option)
- Q428/7, W121/Z-S, D126, D510/B, T401/8, T602/8 (Extension of frequency range from mid-infrared to visible range)
- A670/Z-R, A670-L, A672-K, A686, D424/3, A605, A616, A675 (HYPERION 2000 FTIR microscope with accessories)
- A110, F352, S316/7, F131-3, F505, S950+, A105-x, 17378, 1002709 (additional hard- and software options are available)



evaluation of measured area is done automatically afterwards within easy-to-use OPUS/3D software.

The polarization dependence of a specific resonance within the measured area can be therefore visualized very clearly.

## References

- [1] Science 332, 1407 (2011) Na Liu, Mario Hentschel, Thomas Weiss, A. Paul Alivisatos, and Harald Giessen.
- [2] ACS Nano 6(1), 979 (2012) Stefano Cataldo, Jun Zhao, Frank Neubrech, Bettina Frank, Chunjie Zhang, Paul V. Braun, and Harald Giessen.
- [3] SMALL 7, 14 (2011) J.-H. Cho, M. D. Keung, N. Verellen, L. Lagae, V. V. Moshchalkov, P. Van Dorpe, and D. H. Gracias.

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