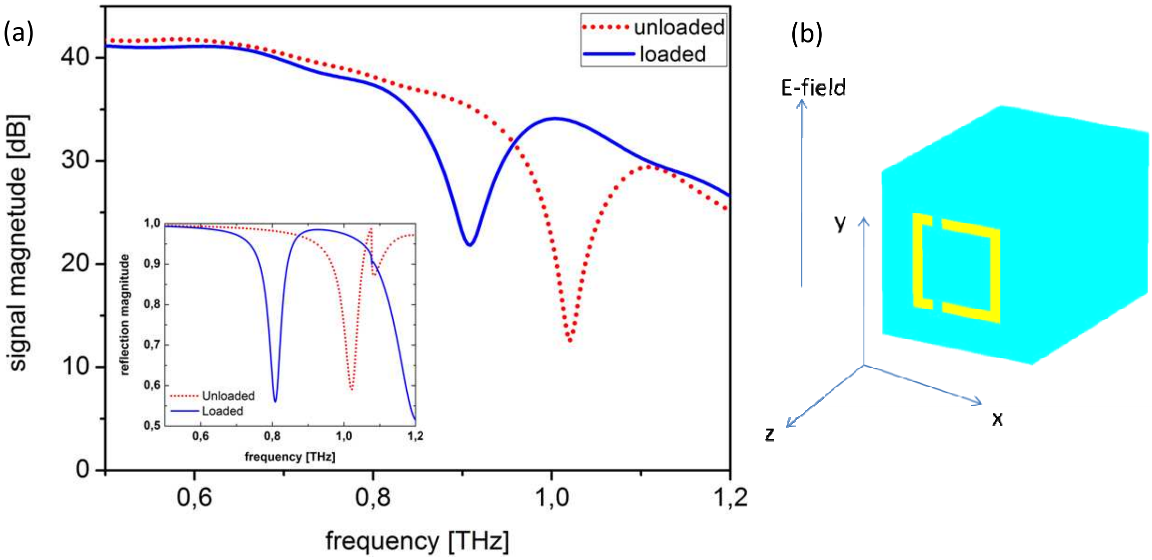

Fig. 2 (a) Transmission data of the loaded (blue) and unloaded FSS (red). Inset: Simulation data for the reflection measurement of the complementary FSS. (b) Polarization and axis definition. Pos. angles are counted clockwise. The THz photons are moving in neg. z-direction.

The origin of the strong and narrow spectral response of the ADSRR is traced to the so-called “trapped modes” [5]. These trapped modes are electromagnetic modes that are weakly coupled to the free space. In symmetrical split rings these modes are inaccessible but they can be exited if the metamaterial´s particles have certain structural asymmetry.

We performed two different measurements to analyse the influence of the incidence angle of the electromagnetic wave to the resonance of the FSS. First we rotated the FSS in the xy-plain around the z-axis (normal rotation) in 10° steps up to 180°; secondly we rotated the sample in the xz-plain around the y-axis (tilt rotation) in 5° steps. The axes are defined in Fig. 2 (b). Both rotations are performed with the THz-focal-spot as the center of the FSS rotation.

The resulting spectra of the normal rotation are plotted in Fig. 3 (a) and (b). Fig. 3 (a) depicts the spectra for different angels from 0° to 90° in 10° steps. The resonance becomes weaker over the angle and vanishes completely at 90°. The angle increases in the direction of the arrow. The graph in the inset is the similar measurement preformed with the unloaded FSS. For both measurements loaded and unloaded we reserved similar results for the notch depth at different resonant frequencies. The spectral position of the resonance is stable while rotating the FSS in normal direction. We were able to simulate the change in the resonance strength as it is shown in Fig. 3 (b). Here the notch depth is plotted over the rotation angle. As simulated the resonance vanishes at 90° and we achieve the maximum value at 0° and 180°. The measurement at 180° is missing in the graph because it is disturbed by any reason and could not be evaluated.

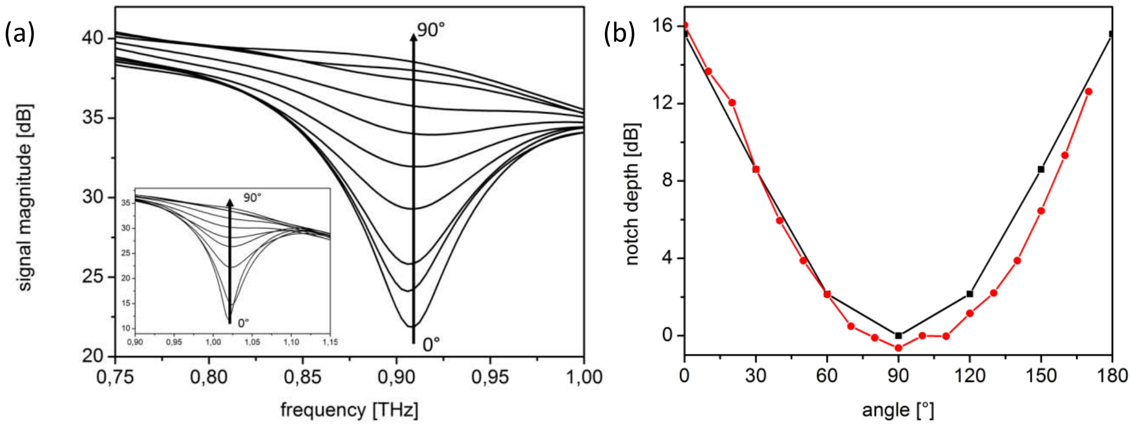

Fig. 3 (a) Spectra for the normal rotation from 0° to 90° for the loaded and unloaded (inset) FSS in 10° steps. (b) Notch depth calculated from the spectra of the resonance, simulated (black) and measured (red) plotted over the rotation angle.

In Fig. 4 the results for the rotation in tilt direction are presented. Fig. 4 (a) depicts the spectra for different tilted angles. To clearly arrange them they are split of into positive angle direction in the main graph and negative angle direction in the inset. The solid line is in both cases the 0° angle. The angle increases in the particular direction in 15° steps in the following sequence: dashed, dot-dashed and dotted lines. The data is plotted in 15° steps but we performed the measurement in 5° steps in both directions up to 45°. The data from the maximum notch depth and the spectral position of that notch are extracted and plotted in Fig. 4 (b). The maximum notch depth (black) increases from -45° to +10° and becomes relatively stable for higher angles. The spectral position where the resonance occurs rises linearly over the rotation angle from 0.99 THz to 1.05 THz.

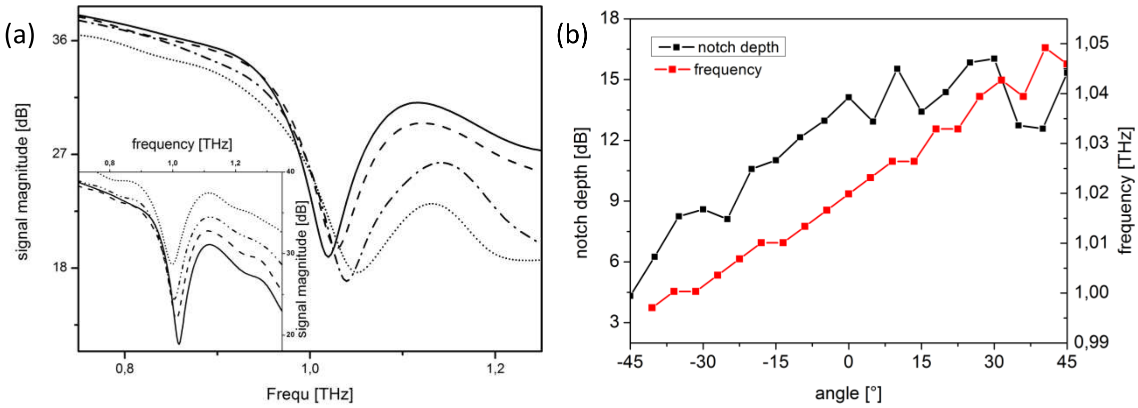

Fig. 4 (a) Spectra for the tilt rotation in positive and negative (inset) direction in 15° steps. 0°=solid, 15°=dashed, 30° dot-dashed and 45°=dotted line. (b) The notch depth (black) and frequency (red) plotted over the angle.

These two effects, the shift in the spectral position and the changing in the notch depth, could not be simulated by us so far. On that point the cooperative work between the „Solid State Spectroscopy Group" of Prof. Tanaka in Kyoto and the „Experimentelle-Halbleiterphysik-Arbeitsgruppe" of Prof. Koch in Marburg will be continued. Hopefully we will be able to publish our results if some additional measurements and simulations in Kyoto and Marburg are going to be performed.

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