Detailed mode profile for the excitation of circulating currents (magnetic dipole mode) by the incident electric field was studied in the literature [22, 23]. We utilized the magnetic dipole mode in our designs. In Fig. 4, the E- field amplitude, and power flow at around the center frequency (225 THz) for the composite absorber were shown. We saw the localization of the incident power between the silver metal layer and split ring resonator layer. The peak power enhancement at the dielectric region was quite high. From quantitative calculations, we discovered that nearly all of the power was absorbed by the metallic parts.

7. Oblique Response

In all the data presented so far, we only characterized the absorber for normal incidence. For the oblique illumination study, we investigated the incidence angles of 20°, 40°, 60°, and 80° in the x-z and y-z planes. Figure 5 shows the spectral response for several angles of incidence: the peak absorption frequency changes and remains more than 70%, and up to a 60° angle of incidence. For oblique illumination, the excitation of SRRs is partially electrically and partially magnetically originated. The details of orientation dependent excitation have been investigated in the literature at the microwave and optical frequencies [20]. There was a slight shift of the operation frequency that slightly decreased the operation bandwidth. Even though the operation frequency of the absorber changed slightly, the absorption values remained large for up to 60° at the x-y and y-z planes.

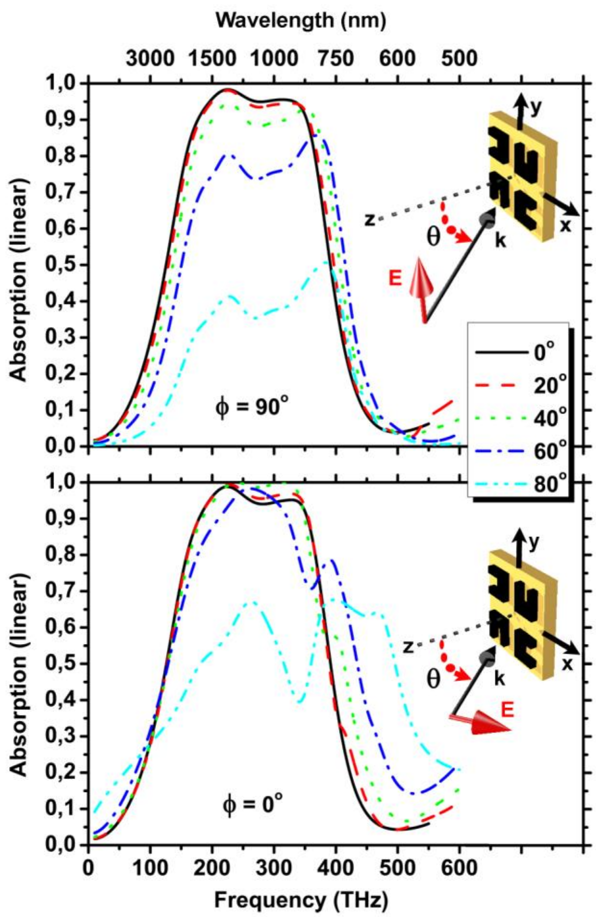

Fig. 5. Simulated absorption response of the SRR based metamaterial absorber for several incidence angles.

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8. Conclusions

We demonstrated metamaterial incorporated broadband absorber configurations operating at the optical regime. For a metal backed metamaterial absorber, the relation between the electrical thickness and the absorbance peak was studied. The origin of the absorbance was proven to be the magnetic resonance of the constituting artificial magnetic material inclusions. We achieved an almost full absorption with a 42% fractional bandwidth by using sub-wavelength SRRs. The total electrical thickness was approximately $\lambda/6$. The broadband absorber composed of an electrical screen in addition to the magnetic metamaterial screen and provided polarization independent and a nearly omnidirectional response. We achieved a minimum absorption of 70% for incidence angles up to 60°. These absorbers provide controllable thermal absorption and thereby controllable thermal emission. They should be useful for thermal photovoltaic, thermal sensor, and camouflage applications.

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