Micromachined Silicon Integrating Cavities for Far-Infrared Bolometer Arrays

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Introduction: Cryogenic radiation detectors using superconducting Transition Edge Sensors (TES) are widely used in astronomical observatories from the millimetre-wave region through hard X-rays[1]. They will provide the sensitivity needed by the next generation of space-based instruments for infrared astronomy, such as SAFARI[2]. In order to reach the target sensitivity (NEP~0.2 aW/√Hz) the nitride legs supporting the island containing the TES and absorbing film must be made extremely long to minimize the thermal conductance (Fig. 1). This leads to low filling factors.

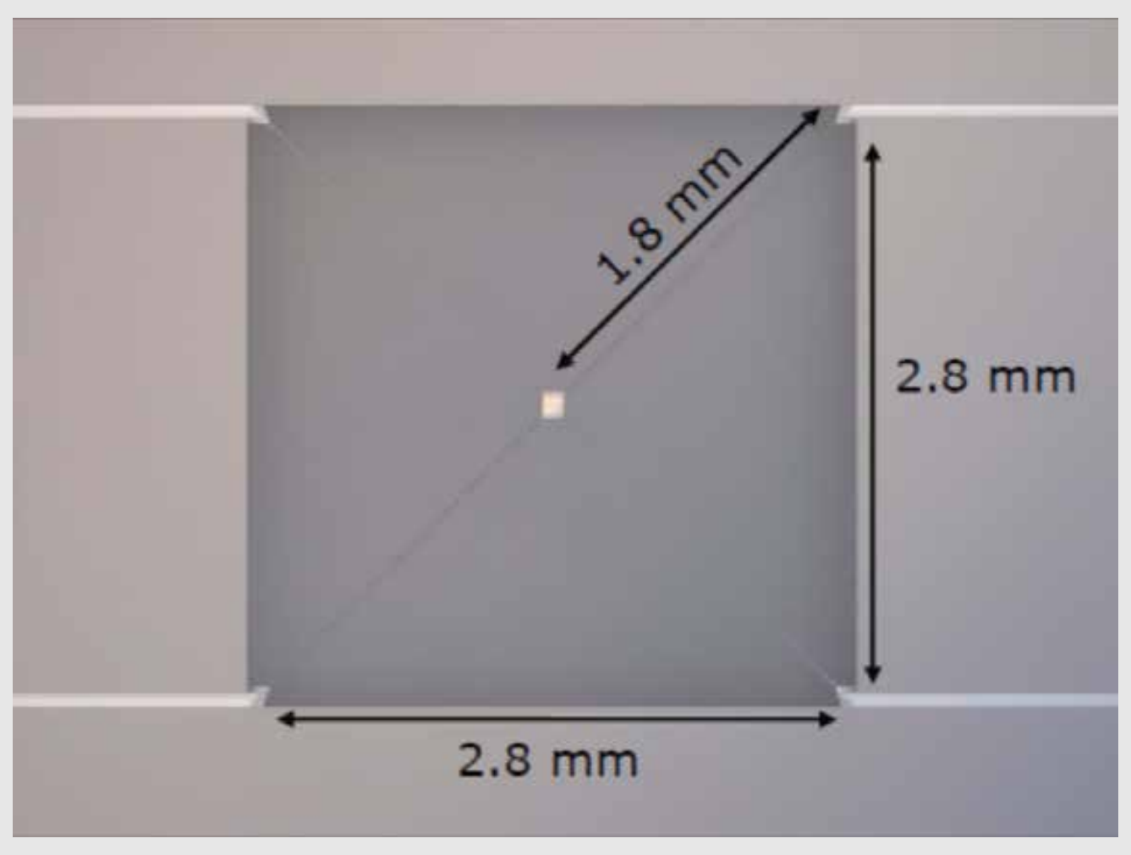

Figure 1 A typical low-NEP TES bolometer. Note how long the legs are compared with the island that carries the radiation absorber.

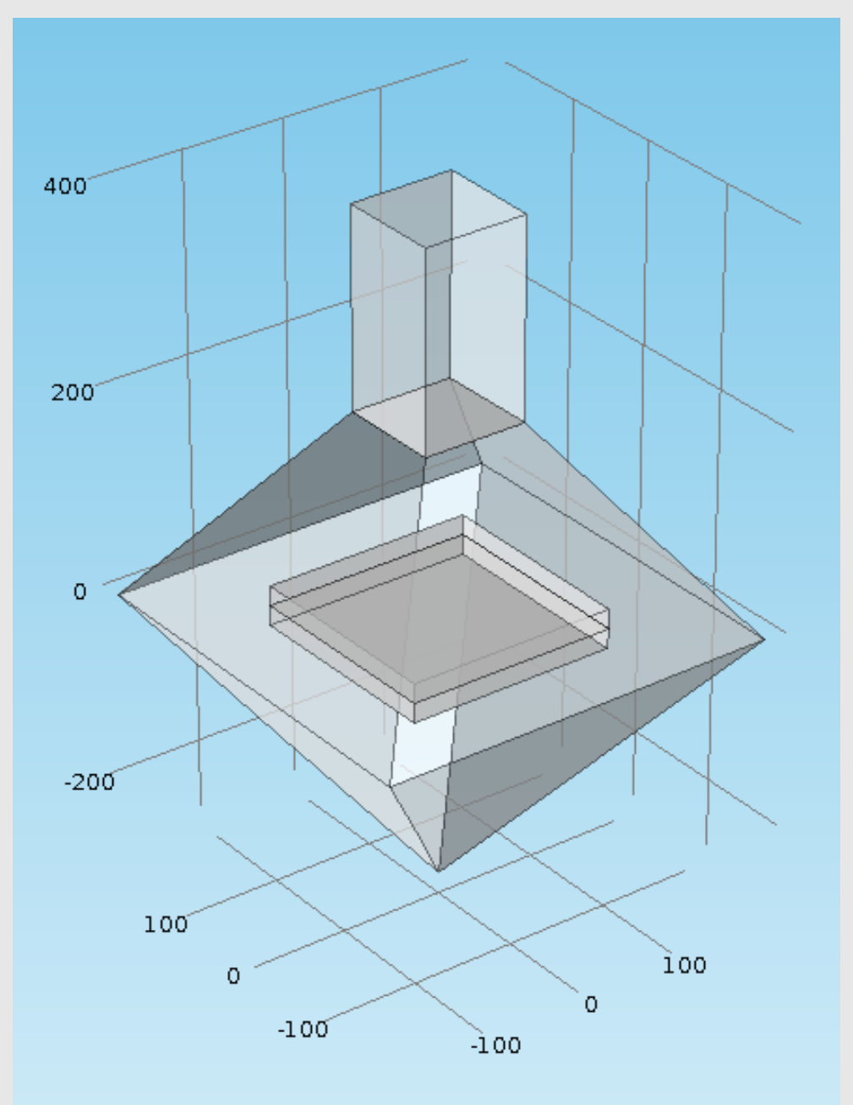

Figure 2 Model of a simple pyramidal integrating cavity. Dimensions are in µm.

Aiming for a flat, broadband response, we are investigating a gold-plated silicon integrating cavity (instead of the usual resonant backshort) for coupling radiation to the bolometer. The cavity is formed from two pyramidal pits made by anisotropic etching of single-crystal silicon. The cavity is fed by a square waveguide created in the upper wafer by deep reactive ion etching. Arrays of such cavities could be stacked to achieve denser packing of the TES bolometers in the focal plane[3].

Computational Method: Figures 2 and 3 show a model of a simple pyramidal integrating cavity fed by a square waveguide. A port on the waveguide entrance is excited with the fundamental TE_{10} mode and an input power of 1 W. The walls of the cavity are modelled as perfectly conducting boundaries. The 377-Ω/□ metal-film absorber is modelled as a transition boundary condition and is surrounded by a rectangular air-box to help the meshing. The model is solved for a range of frequencies using a full parametric sweep, recalculating the mesh for each frequency. Integrating the surface resistive losses over the absorber gives the absorbed power, and $|S_{11}|^2$ gives the reflected power. Their sum gives an estimate of the error in the result.

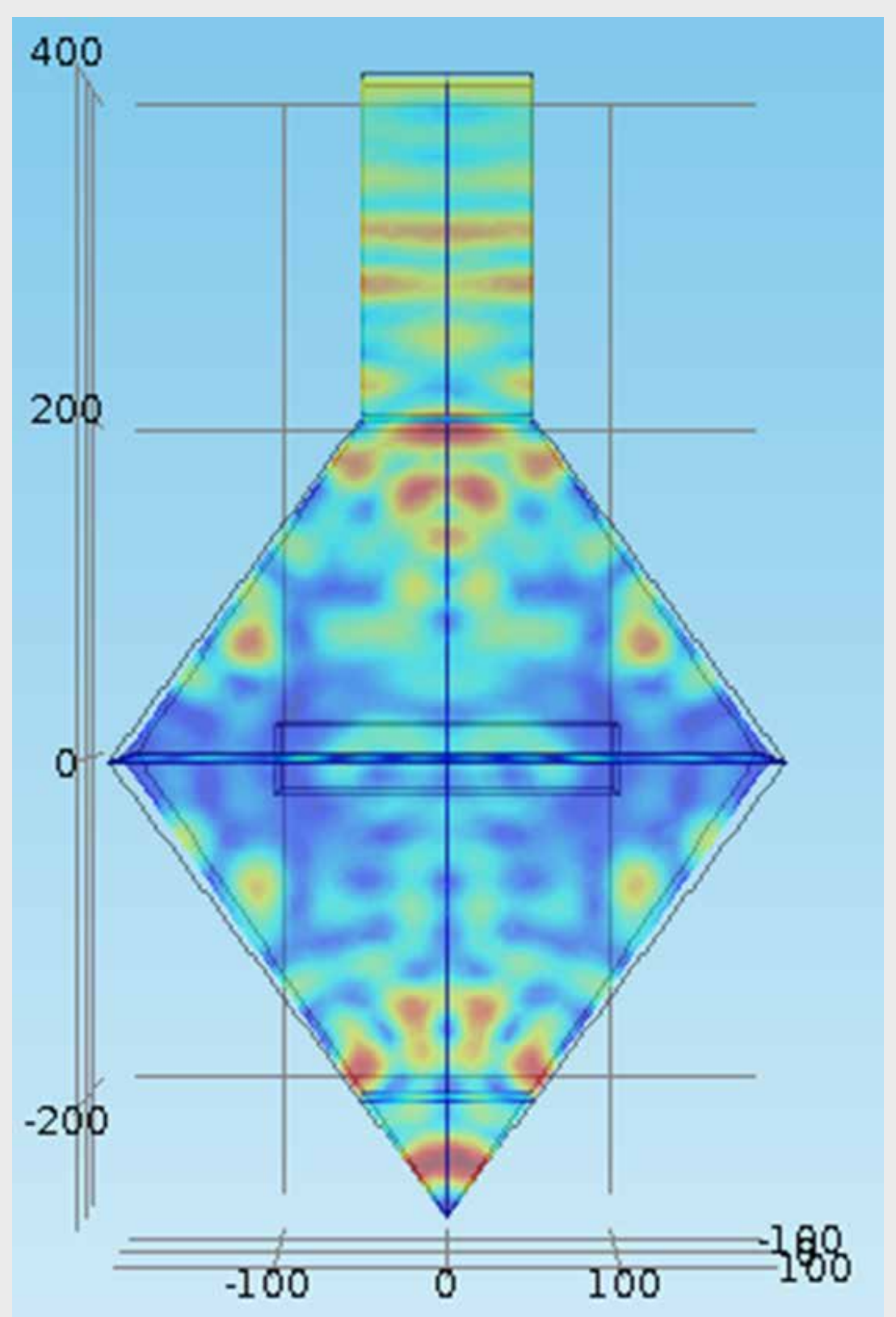

Figure 3 Magnitude of electric field in simple pyramidal model at 4.3 THz. Dimensions are in µm.

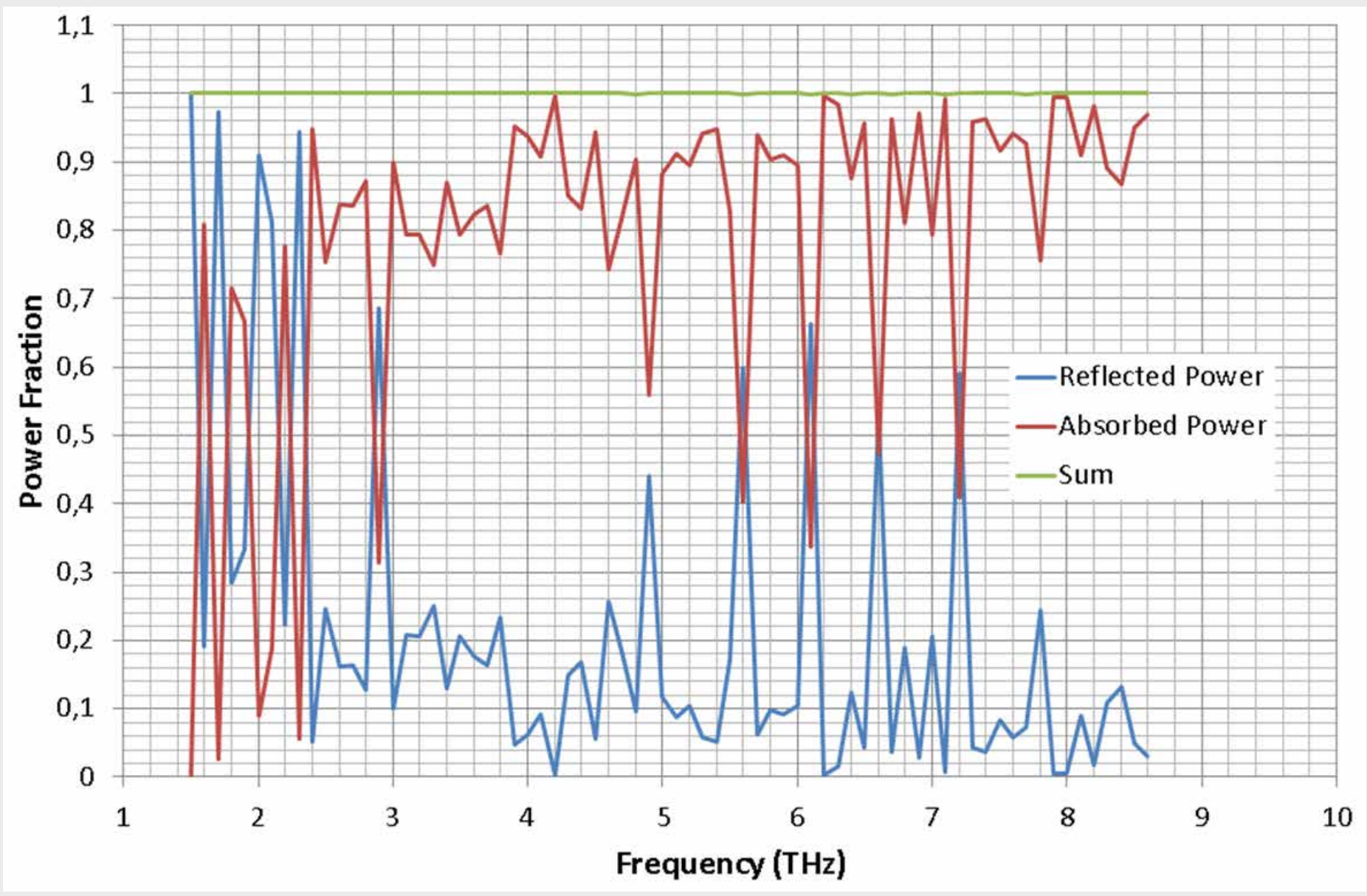

Figure 4 Fraction of power reflected and absorbed and their sum at different frequencies for simple pyramidal cavity.

Results: The simple pyramidal cavity has reasonable performance but sharp, deep dips in the absorption coefficient. (Fig. 4). We made various combinations of changes to the simple cavity and compared the results. Our goal was a high absorption efficiency over a broad band with minimal spectral features. We found that offsetting the waveguide to one corner was effective, as was adding a straight section between the top and bottom of the cavity. Reducing the width of the cavity from 400 to about 300 microns also improves the efficiency,, as expected; the absorber is 200 µm square. Making the top surface of the cavity flat degraded performance as expected, as did moving the absorber up from the bottom of the straight section. Figure 5 shows one of these optimized models. Note the high absorption coefficient over a broad frequency range and the absence of significant resonant features.

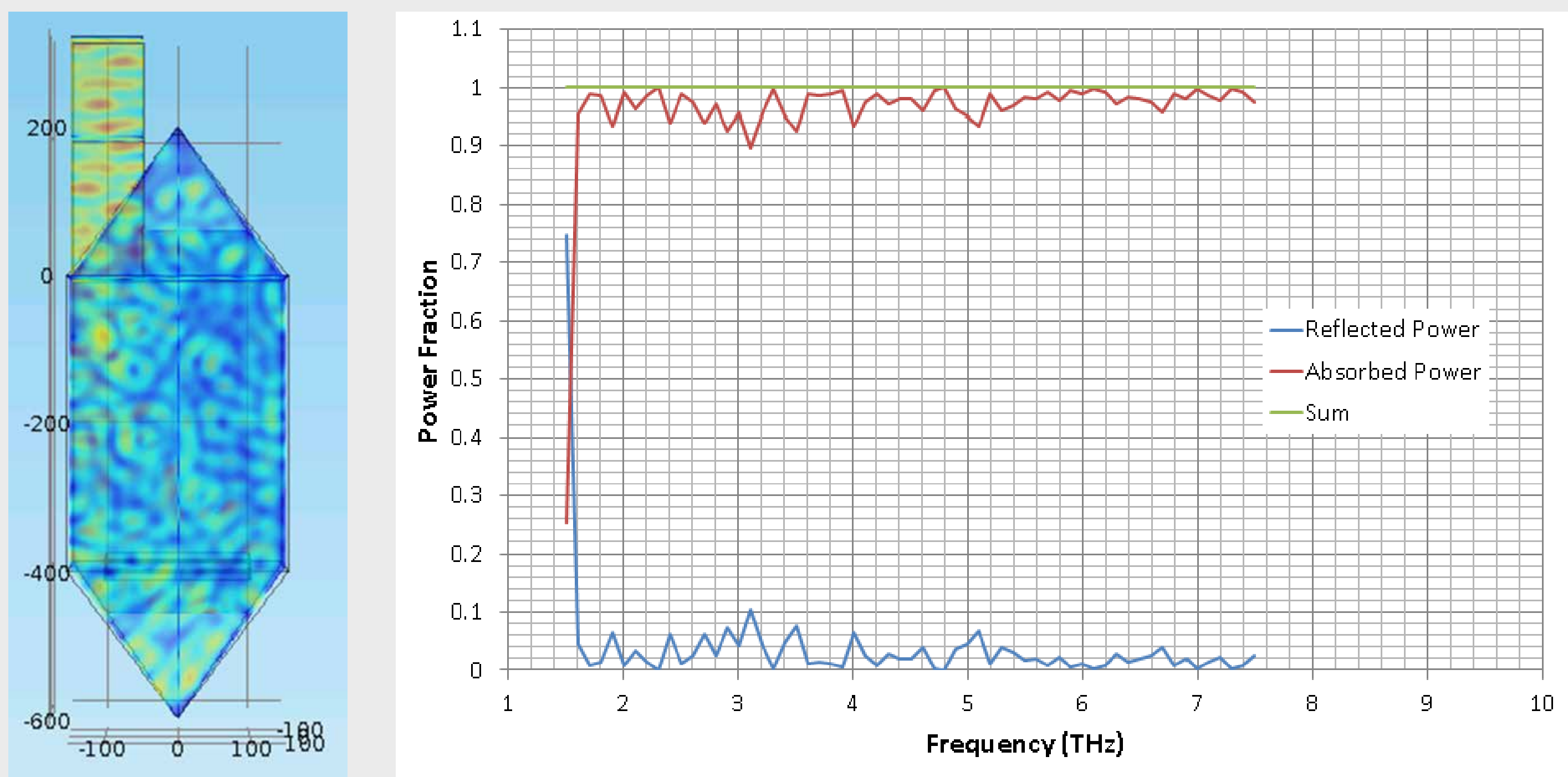

Figure 5 Left: Model of an optimized integrating cavity showing the magnitude of the electric field at 5.3 THz. Dimensions are in µm. **Right:** Fraction of power reflected and absorbed and their sum at different frequencies for optimized pyramidal cavity. The absorption coefficient is higher than 90% from cut-on at 1.5 THz to the highest frequency modelled (7.5 THz)

Conclusions: We have used Comsol Multiphysics® to optimize the design of a micromachined silicon integrating cavity for arrays of far infrred TES bolometers. A cavity with a waveguide offset to one corner and a straight section of a few hundred microns gives the best performance. The performance improvement with the straight section is significant because it means that we can make the cavities with different depths, on the order of a wafer thickness, which makes a focal plane of stacked wafers feasible. Our next step will be to verify these results with W-band scale models.

References:

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3. G. de Lange, M.D. Audley, G. Keizer, S. Doherty, and C. Bracken, “Design description of silicon micro-machined cavity coupled far-infrared bolometer array,” Proc. 25th International Symposium on Space Terahertz Technology, in press (2014)

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