Design and Performance of a Micro-Rectenna Focal Plane Array for Thermal Energy Harvesting

C. Balocco[(1)], Y. Pan[(1)], M. C. Rosamond [(2)] and E. H. Linfield [(2)]
(1) School of Engineering and Computer Sciences, Durham University, Durham, DH1 2PN, UK
(2) School of Electronic and Electrical Engineering, University of Leeds, Leeds, LS2 9JT, UK

In this paper, we present the design and experimental implementation of a thermal energy harvesting device. Each energy-harvesting unit cell functions as an individual micro-rectenna and, collectively, as a focal plane array (FPA). The FPA is fabricated out of a two-dimensional electron gas (2DEG) in GaAs/AlGaAs quantum well using electron beam lithography (EBL) and photolithography methods, and consists of micro-rectenna unit cells arranged on a square lattice of 11 by 11 elements. The micro-rectenna, consisting of a high-speed diode (self-switching diode) and a broadband bowtie antenna, can convert thermal radiation into dc electric power (Y. Pan, C. V. Powell, A. M. Song and C. Balocco, *Applied Physics Letter*, 105, 253901, 2014).

We also present an analytical model for our rectenna based on Feynman's ratchet and pawl which extract useful work from Brownian motion. The radiation from a blackbody source drives the rectenna out of thermal equilibrium, permitting the rectification of the excess thermal fluctuation from the antenna in the sub-millimeter wave region. Good agreement for the open-circuit voltage and short-circuit current is obtained with the experimental results for the electromagnetic radiation (equivalent blackbody temperatures from 600 to 1000 K) suggesting that the model can be applicable to our device. We characterize the FPA conversion efficiency and angular dependence. The measured half-beam width is approximately 140^{o} that demonstrates the rectenna operating as a wide angle antenna. We also design and manufacture a dielectric micro-lens array. By integrating the lens array with our energy harvesting FPA, we improve the coupling efficiency of the incident power into the micro-rectennas and thus the power conversion efficiency. Our device holds potential for efficient and practical electromagnetic energy harvesting, notably for wasted heat recovery applications.