Seebeck Nanoantennas for Solar Energy Harvesting

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Outline

• Introduction to Nanoantennas (How everything started).
• Antenna-coupled microbolometers.
• Applications to Solar Energy Harvesting.
  • Rectennas.
  • Antenna-coupled thermocouples.
  • Seebeck Nanoantennas.
• Other Applications.
• Conclusions.
Bolometers

- Made of materials with very small thermal capacity and large temperature coefficient of resistance so that the absorbed radiation produces a large change in resistance.
- They are operated by passing a bias current through the detector and monitoring the output voltage.

Bolometer Detector Circuit with bridge configuration for dc operation.

AC-coupled Bolometer Detector Circuit
Antenna-coupled microbolometers

F.J. González, G.D. Boreman, “Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas”, *Infrared Physics and Technology*, vol. 46, no. 5, (2005), 418-428.
Antenna-coupled microbolometers

Dipole

Square-Spirals

Bowtie

Log-Periodic

F. J. Gonzalez, E. Briones, E. Tucker, G. Boreman, M. Raschke, “Electric Near-Field Distribution of Optical Nanoantennas”, Frontiers in Optics/Laser Science XXIX (FiO/LS), October 2013, Orlando, Florida.
Cambridge EBMF 10.5/CS Electron Beam Lithography System

Microbolometer fabricated using EBL
The sensitive element is a NB patch of 800 nm × 200 nm
Liftoff

(a) PMMA

P(MMA-co-MAA)

(b) Bilayer Profile

Finished Device
Characterization
Characterization
F.J. González, G.D. Boreman, “Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas”, *Infrared Physics and Technology*, vol. 46, no. 5, (2005), 418-428.
2D Scan in the Infrared
Deconvolution

F.J. González, G.D. Boreman, “Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas”, Infrared Physics and Technology, vol. 46, no. 5, (2005), 418-428.
Integration to ROICs
Integration to ROIC’s
Integration to ROIC’s
Integration to ROIC’s

8x8 Array of Spiral Antennas

8x8 Array of Log-Periodic Antennas
Integration to ROIC’s

F.J. González, J.L. Porter, G. D. Boreman, “Antenna-coupled Infrared Focal Plane Array”, *Microwave and Optical Technology Letters*, Vol. 48 No. 1, (2006), 165-166.

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Advantages

Array of nanoantennas can be fabricated on flexible substrates and placed on clothing or rolls that can later be extended for charging portable equipment.
Nanoantennas can be tuned to harvest energy at infrared and longer wavelengths, which are not used by PV.
FEM Simulations

Numerical simulations of the far-infrared antenna-coupled microbolometer were performed using COMSOL Multiphysics.
Material Parameters

\( n \) and \( k \) values for gold, aluminum, copper and nickel films as a function of frequency obtained using a J.A. Woollam infrared variable angle spectroscopic ellipsometer (IR-VASE).

F.J. González, J. Alda, J. Simón, J. Ginn and G. Boreman, “The effect of metal dispersion on the resonance of antennas at infrared frequencies”, Infrared Physics and Technology, vol. 52, No. 1, (2009), 48–51.
FEM Simulations
FEM Simulations
Detection Mechanism
Harvesting mechanism

Rectennas

MOM Diodes

- Low efficiency
- High impedance, which creates an impedance mismatch with the antenna reducing its efficiency.
- Efficiency in the 10^-6-10^-9.

E. Briones, J. Alda and F. J. González, “Conversion efficiency of broad-band rectennas for solar energy harvesting applications”, Optics Express, (21) S3, pp. A412–A418, (2013).
Seebeck Nanoantennas

Single element nanoantenna

Array of Nanoantennas

Materials: Ti/Ni (S_Ni = -15, S_Ti = 7.19)

$\Delta V = 3.6 \mu V$

Signal increase by using an array

$\Delta V = 26 \mu V$
Antenna-coupled Thermocouples

- Nanorectennas are actually thermocouples (Reference).

G.P. Szakmany, P.M. Krenz, A.O. Orlov, G.H. Bernstein, W. Porod, “Antenna-Coupled Nanowire Thermocouples for Infrared Detection,” IEEE Transactions on Nanotechnology, 12 (2), pp. 163-167, (2013).
Single-metal nanothermocouples

The hot and cold junctions of the thermocouple are formed between the narrow and wide wire segments. Fabrication complexity is greatly reduced compared to bi-metallic thermocouples, and might point the way to large-scale fabrication.

G.P. Szakmany, P.M. Krenz, A.O. Orlov, G.H. Bernstein, W. Porod, “Nanoantenna Integrated Infrared Thermoelectric Converter,” Proceedings of the 14th IEEE International Conference on Nanotechnology Toronto, Canada, August 18-21, 2014
E. Briones, A. Cuadrado, J. Briones, J.C. Martínez-Antón, S. McMurtry, M. Hehn, F. Montaigne, J. Alda and F. J. González, “Seebeck nanoantennas for solar energy harvesting,” Applied Physics Letters, 105, 093108, (2014).
Materials:

Ti/Ni \((S_{Ni} = -15, S_{Ti} = 7.19)\)

\[ \Delta V = 5.74 \, \mu V \]

\[ \Delta V = 9.08 \, \mu V \]

E. Briones, A. Cuadrado, J. Briones, J.C. Martínez-Antón, S. McMurtry, M. Hehn, F. Montaigne, J. Alda and F. J. González, “Seebeck nanoantennas for solar energy harvesting,” Applied Physics Letters, 105, 093108, (2014).
Other Applications
A. Cuadrado, E. Briones, F. J. González and J. Alda, “Polarimetric pixel using Seebeck nanoantennas,” Optics Express, 22 (11), pp.13835-13845, (2014)
A. Cuadrado, E. Briones, F. J. González and J. Alda, “Polarimetric pixel using Seebeck nanoantennas,” *Optics Express*, 22 (11), pp.13835-13845, (2014)
Polarization detection

A. Cuadrado, E. Briones, F. J. González and J. Alda, “Polarimetric pixel using Seebeck nanoantennas,” Optics Express, 22 (11), pp.13835-13845, (2014)
New Fabrication Methods

Nanoimprint Lithography

Electrochemical deposition
• Antenna-coupled microbolometers can be used for infrared detection and can be integrated into ROICs to make IR-FPA.
• Rectennas would probably have extremely low efficiencies making them impractical for energy harvesting applications.
• Nanoantennas can be used to harvest solar energy by using them in a Seebeck-Nanoantenna configuration.
• Measurements will show what would be the real efficiency of this devices and would indicate the possible applications.
Collaborators

Prof. Glenn Boreman
(UNCC)

Prof. Javier Alda
(UCM)