Title: Development of Quantum Well Thermocouples in Thermoelectric Energy Harvesters

Name: S. M. Yang
National Cheng Kung University, Taiwan, ROC

Silicon-based design has the advantage of using semiconductor thin-film process for batch production; however, the generator performance is often limited by the poor figure-of-merit in silicon. This work aims at improving the energy harvesting performance of thermoelectric generators by using low-dimensional thermoelectric materials in quantum wells for the thermocouples. CMOS based thermoelectric generators have achieved significant progress from geometry-design point of view. This work aims at improving the harvesting performance from materal-design point of view. A micro thermoelectric generator combining the conventional in-plane and cross-plane designs is adopted so that the heat flux from the top to bottom surface is confined passing through the in-plane quantum well thermocouples. The design integrates the state-of-the-art semiconductor CMOS process and low-dimension $Si_{0.9}Ge_{0.1}$ quantum well for optimal performance. The efficiency of thermoelectric material is described by the dimensionless figure-of-merit $ZT = \sigma S^2 T / k$, and the challenge is to have high ZT by increasing S and σ while simultaneously decreasing k. A relaxation model is applied to analyze the characteristic length of the $Si_{0.9}Ge_{0.1}$ quantum well. Analyses show that the quantum confinement effect and spatial confinement effect can increase ZT significantly by higher electrical conductivity and Seebeck coefficient. In addition, the spatial confinement effect by the phonons scattered at the boundaries also reduces the thermal conductivity. The ZT of a $Si_{0.9}Ge_{0.1}$ quantum well in the characteristic length 50 nm is about 4.5 times of the bulk material, i.e., $Z_{2D}T = 0.566$ at 300 ^{o}K. This figure-of-merit is higher that the bulk $Si_{0.9}Ge_{0.1}$ at $Z_{3D}T = 0.125$ and much higher than the P- and N-poly Si at $ZT = 0.046$ and 0.038, respectively, and such improvement from quantum well is critical to higher generator performance. Experimental verification shows the design achieves superior generator performance compared with those in the literature.

Biography

Professor Yang has been developing thermoelectric generators since 2009.

Presenting author details
Full name: S. M. Yang
Category: (Oral presentation/Poster presentation)