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The "Scanning Hot Probe" technique for thermoelectric properties measurement of nanostructured thin films

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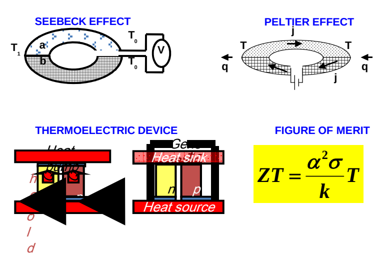
Abstract

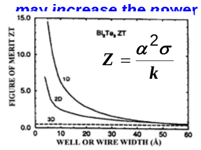
A variety of SThM methods have been explored since the invention of the scanning tunneling microscope(STM) and the atomic force microscope(AFM).This work reports on thermoelectric measurements in nanostructured thin films using a scanning hot probe technique. In this method a resistively heated thermal probe of an Atomic Force Microscope (AFM) is brought in contact with the sample surface giving rise to a temperature gradient and a Seebeck voltage in the specimen. The average temperature rise of the probe is determined from the change in its electrical resistance. The heat transfer rate between the probe and the sample is estimated using a heat transfer model that takes into account the major heat transfer mechanisms in the system. The heat transfer mechanism between tip sample was investigated in detail. The relative contribution of solid-solid contact , water meniscus, and air to the heat transfer mechanism was determined for the kind of tip that we have used in our experiments. The effective contact area radius between tip and sample is 2 microns. The thermal conductivity is determined from the measured thermal resistance of the film. The Seebeck coefficient value is calculated using the measured temperature drop and the Seebeck voltage in the plane of the sample. The method is calibrated on glass and bismuth telluride substrates. The Seebeck coefficient is calculated and validated by measurements on BiTe bulk sample. After this the Seebeck coefficient was measured on a BiTe nanoparticles thin film deposited on glass. The thermal conductivity for the same film was measured. Experimental results are presented for the thermal resistance and Seebeck coefficient of thermoelectric films composed of bismuth telluride and lead telluride nanoparticles and nanorods deposited on a glass substrates.

Thermoelectric energy conversion in nanostructures



• Boundary and interface scattering reduces the thermal conductivity

• Quantum confinement may increase the power

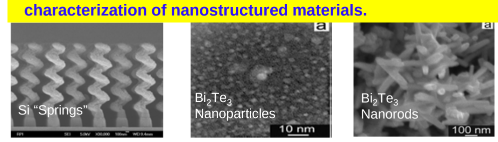


Motivation and Goal

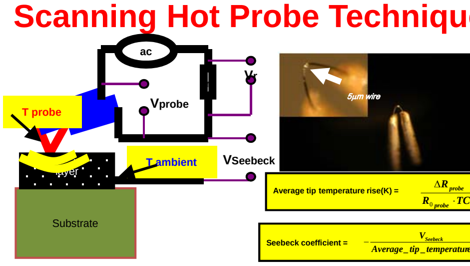
• Advances in materials science lead to synthesis of a variety of nanostructures with potential use in thermoelectric applications.

• Experimental investigation plays a critical role in understanding the relationship between structure and transport properties.

• Develop fast and reliable methods for thermoelectric properties characterization of nanostructured materials.



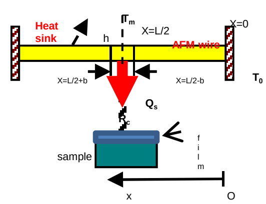
Scanning Hot Probe Technique



Average tip temperature rise(K) = $\frac{\Delta R_{probe}}{R_{0\,probe} \cdot TCR}$

Seebeck coefficient = $-\frac{V_{Seebeck}}{Average\_tip\_temperature\_rise}$

Theoretical model for the wire in contact with the sample



Wire BC's:

1) At x=0:

$T^*=0$

2) At x=L/2-b

$$-kA\frac{\partial T^*}{\partial x}\bigg|_{x=l/2-d} + P_t = \frac{Q_s}{2}$$

The Heat conduction equation is:

$$\frac{d^2T^*}{dx^2} - \boxed{\left(\frac{2h}{kr} - \frac{I^2\rho_0\alpha}{k\pi^2r^4} + \frac{8\varepsilon\sigma T_0^3}{kr}\right)} \cdot T^* + \boxed{\frac{I^2\rho_0}{k\pi^2r^4}} = 0$$

S λ

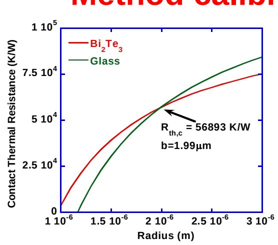
With solution:

$$T^* = c_1e^{\lambda x} + c_2e^{-\lambda x} + \frac{S}{\lambda^2}$$

Where c_1 , c_2 are determined from the BCs

S and λ are the corresponding coefficients in the equation

Method calibration



-Model used to fit of the tip thermal resistance for two bulk samples.

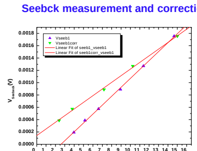
-Assumption: Tip –Sample contact resistance the same.

-Specific contact thermal resistance about 10^{-7} Km^2/W which is ~ interface between two dissimilar materials.

-Effective contact radius is much larger than solid contact (~10nm).

Seebeck and thermal measurements on BiTe nanoparticles film on glass

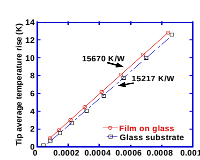
Seebck measurement and correction



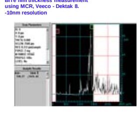
Seebeck PbTe nanoparticles=+174µV/K

Bulk BiTe Seebeck=-212µV/K

Tip thermal resistance calculation of glass and BiTe film on glass



BiTe film thickness measurement using MCR, Veeco - Dektak 8. -10nm resolution

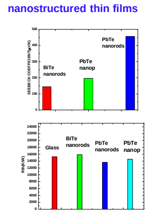


Thickness = 200-400nm

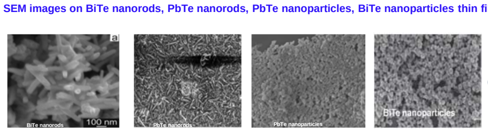
$k_{BiTe\ film}$ = 0.3-0.6 W/mK

Bulk BiTe k = 1.5W/mK

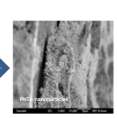
Thermal resistance and Seebeck coefficient for nanostructured thin films



SEM images on BiTe nanorods, PbTe nanorods, PbTe nanoparticles, BiTe nanoparticles thin films



The thermal conductivity for the films on the left hand side could not be measured due to the non uniformity in films thickness.



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