Effect of phonon confinement on heat dissipation in ridges

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We have investigated experimentally the effect of lateral confinement of acoustic phonons in ridges as a function of the temperature. Electrical methods are used to generate phonons in 100nm large nanostructures and to probe the nanostructure temperature in the same time, what allows tracking the heat flux generated and its possible deviation to Fourier diffusive heat conduction.

It is now well-established that Fourier's law of heat diffusion in solids breaks down when device sizes reaches the nanometer-scale [1]. Detailed studies of the characteristic lengths where the law has to be replaced or modified are required as these lengths might depend on the considered device geometries.

We have fabricated special devices made of nanostructured ridges on top of planar substrate as represented on Figure 1. The top of a ridge is a wire made either of metal or of doped silicon that acts as a heater and as a thermometer in the same time. The lower part that supports the wire is made of an etched part of the wafer substrate. This type of structure enables to generate phonons in the ridge and to measure the heat flux flowing to the substrate.

Different electrical methods such as the 3ω method [2] are used to heat the wire. The goal is then to measure a wire-voltage component (dc or ac) proportional to the wire temperature. A model enables then to link the wire temperature to the heat flux transmitted to the substrate. In addition to the localized heat source effect due to the sub-mean free path size of the source [3], we have investigated experimentally the consequences of the fact that the source cannot be considered as a proper heat bath at equilibrium.

We have quantified the effect as a function of the two characteristic numbers that can be associated with the problem, namely the constriction Knudsen number describing the transmission of the phonons and the nanostructure Knudsen number characterizing the nonequilibrium of the source. We compare our results with those of a recent theoretical paper [4] based on the ballistic-diffusive equations. The determination of the mean free paths of phonons as a function of the frequency remains a key point due to the consequences for heat transport and thermal management [1].

We observe a strong decrease of the thermal conductance through the ridge in comparison to a prediction based on the Fourier diffusive as expected. But, more strikingly, we also observe a decrease in comparison to the ballistic prediction. We aim at ascribing part of this decrease to an effect of phonon confinement in the ridge.

References

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Figures

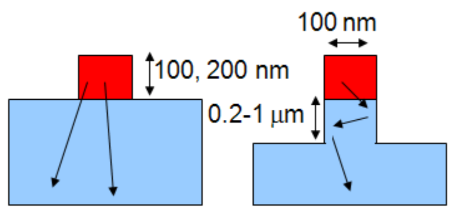

Fig.1: *Schematic of the nanostructures*

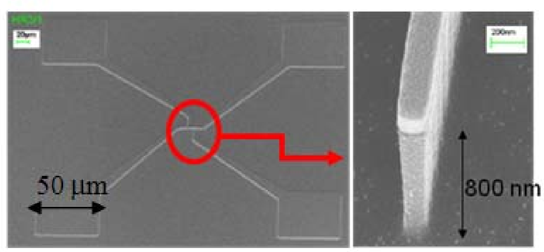

Fig.2: *Electrical accesses and ridge before mask removal*

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