HIGH FREQUENCY PHONON TRANSMISSION THROUGH AMORPHOUS FILMS

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Introduction

The low temperature anomalies of amorphous materials particulary the thermal conductivity "plateau" between 5K and 10K are explained to be due to inelastic Raman scattering of phonons at two level systems (TLS) [1] or to localized phonon modes on fractal structures [2]. The basic idea with respect to the TLS model is that an amorphous solid is characterized by a number of atoms which have two or more stable positions. The atoms can therefore be described as moving in a "double-well" potential forming TLS by tunnel splitting. In order to obtain detailed information on phonon scattering processes earlier phonon spectroscopy measurements were performed on thin amorphous SiO_2 films [3]. The accessible frequency range so far was limited by the usage of Sn tunnel junctions as phonon generator and ranged from 100 GHz to 300 GHz. We now report on phonon spectroscopy measurements in the frequency range from 300 GHz - 1THz on thin amorphous films of several materials (i.e. e-beam evaporated SiO_2, α-Si and α-Ge). Some films were prepared in a residual gas atmosphere as H_2, O_2 and N_2.

Experimental results

Fig. 1 shows the phonon transmission spectra of two identical Si samples which were covered with SiO_2 monolayers of different thickness under the Al generator . The signals were adjusted to identical step hight at the detector threshold. The signal amplitudes coincide up to 380-400 GHz and are differently reduced for higher frequencies with stronger reduction for a larger thickness of the SiO_2 layer. The oxygen absorption line of the interstitial oxygen in the substrate at 875 GHz is also reduced with increasing layer thickness. This observation can be explained by phonon scattering processes with inelastic contributions above 400 GHz in the SiO_2 layer. Fig 2 shows the phonon transmission spectra of two amorphous Si films with thicknesses of 19 and 38 nm respectivily. The signal amplitude apparently is not affected by the film thickness. In Fig 3 the phonon transmission spectrum of a 28 nm Si sample which is prepared by HF sputtering in a H_2 atmosphere (lower trace) is compared with the spectrum of the bare substrate. The spectrum of the Si:H_2 sample shows the same characteristics as the SiO_2 layers. The phonon transmission spectrum of a 40 nm pure α-Si layer and for comparasion of a 40 nm Si monolayer which is evaporated in an O_2 atmosphere of $2 \cdot 10^{-5}$ mbar is shown in Fig 4. The spectrum of the Si:O_2 film corresponds again to phonon scattering with strong inelastic contributions above 400 GHz. This is not observed for Si evaporated in a N_2 atmosphere. We obtained corresponding results for α-Ge and for Ge evaporated in a O_2 or alternatively N_2 atmosphere.

Discussion

The transition from crystalline Si or Ge to the amorphous state can be described as the transition in a disordered "frozen liquid" like state in which some Si atoms are linked to less than four neighbour atoms. The resulting "not saturated bonds" are known to form trapping centers for electrons leading to a reduction of the electron conductivity [4]. The conductivity can be increased by addition of hydrogen which occupies the "non saturated" orbitals. Such saturated Si-H bonds can therefore be expected also to exist in our Si films prepared in an H_2 atmosphere. For similar reason in Si and Ge samples evaporated in an O_2 atmosphere the existence of Si-O-Si respective Ge-O-Ge bonds are possible. In contrast evaporation of Si or Ge in a N_2 atmosphere as an inert gas does not lead to corresponding saturated bonds. The amorphous state of SiO_2 can be imagined as to be partly related to the cristobalite structure. The cristobalite structure is cubic as Si but with one oxygen atom placed in the bond axis between two Si atoms. The amorphous state can be imagined to form corresponding Si-O-Si bonds as already discussed. These Si-O-Si bonds form TLS . We ascribe the observed strong inelastic phonon scattering above 400 GHz in Si:H_2, Si:O_2 and SiO_2 to inelastic scattering processes at these TLS. In pure Si and Ge or in Si and Ge evaporated in a N_2 atmosphere such saturated bonds do not exist and therefore no inelastic phonon scattering is expected in accord with our experimental results. The onset frequency of the inelastic scattering process at 380 GHz observed in our measurements corresponds to the thermal phonon peak position at a temperature of 4.8 K. This coincides with the onset of the "thermal conductivity plateau" in SiO_2 and other amorphous materials and appears to be related to the observed inelastic phonon scattering at 380 GHz. We therefore expect that inelastic processes play a considerable role in the origins of the thermal conductivity plateau. Indeed for α-Ge in which no inelastic phonon scattering was observed in our experiments the thermal conductivity only flattens off around 3K but does not form a "plateau" as known from SiO_2 or other amorphous materials [5].

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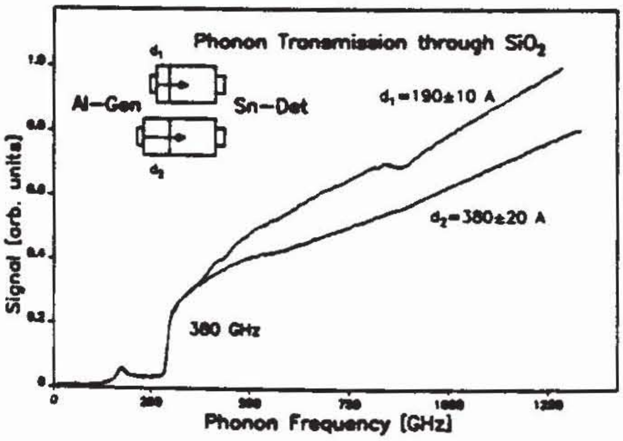

Fig 1

Phonon transmission through SiO_2

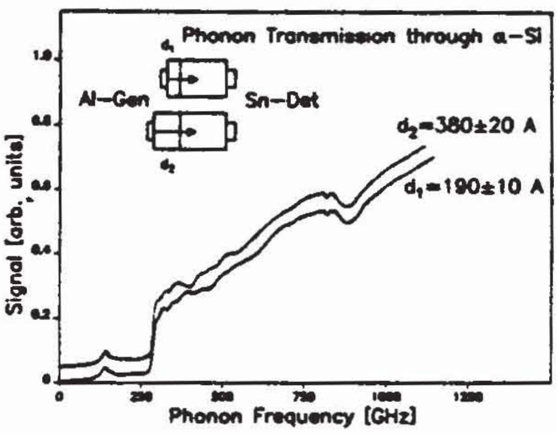

Fig.2

Phonon transmission through α Si

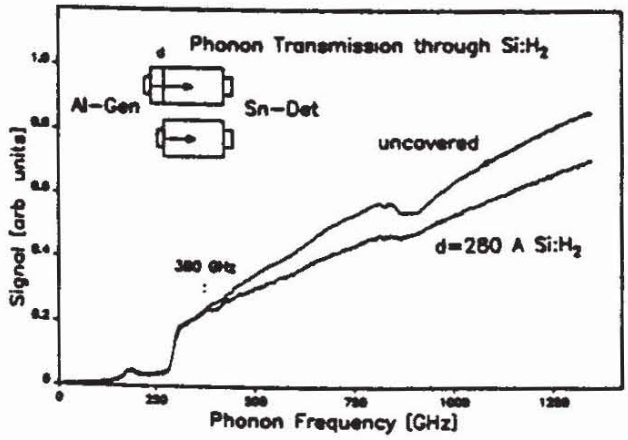

Fig.3

Phonon transmission through Si:H_2

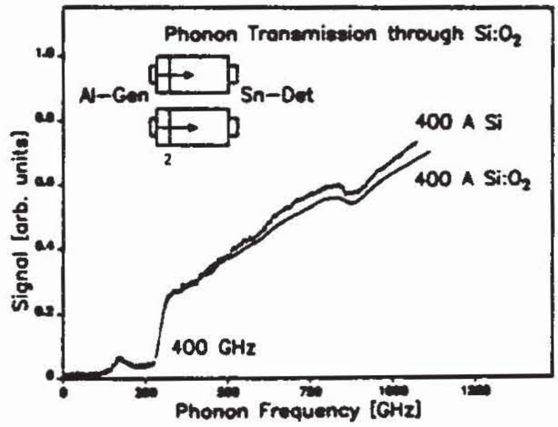

Fig.4

Phonon transmission through Si:O_2