Physica B 194–196 (1994) 1079–1080
North-Holland

PHYSICA B

Low Temperature Measurements of the Dielectric Constant and Loss of Boron Doped Silicon

R. D. Biggar, K. R. Lane, and J. M. Parpia
Department of Physics, Cornell University
Ithaca, New York, 14853, USA

We have measured the capacitance of a silicon wafer contained between two bulk metallic electrodes. The capacitance has a prominent feature which is frequency and magnetic field dependent at a temperature of about 5K for a 0.2Ω-cm nominal resistance sample, and which is seen to be replicated at higher temperature for a 100Ω-cm sample.

1. INTRODUCTION

We have measured the capacitance and loss of a pair of parallel plates containing a single crystal of boron doped silicon as a function of temperature (0.5K to 20K) and of frequency (10Hz to 10kHz). The silicon core was capacitively coupled to ground. Features in capacitance and loss showed a strong dependence on frequency, shifting toward higher temperature as the frequency was increased. A smaller shift was induced by applying a 5.5T magnetic field. The frequency dependence is consistent with previous measurements at higher frequency and lower doping[1, 2]. We also observe a strong dependence on dopant concentration. We associate these features with the metal insulator transition.

2. EXPERIMENTAL DETAILS

The samples were pieces of boron doped silicon with native oxide layers. They were clamped to a grounded metal arm, which also served as a thermal anchor. Insulating tape was placed between the sample and the clamp to avoid grounding the sample in its conducting state. Shielded bulk brass electrodes were held within a millimeter on either side of the sample, but were not in contact with it. The sample was cooled in a ^{3}He refrigerator down to about 0.5K, and the temperature was slowly raised to 20K. Capacitance and loss measurements were made on General Radio 1615-A and Andeen Hagerling 2500A capacitance bridges. The former allowed measurements at frequencies from 10Hz to 10kHz, while the latter was used only for measurements at 1kHz.

3. RESULTS AND ANALYSIS

The dependence of capacitance on temperature has the same form under all conditions. At low temperatures, the capacitance is fairly constant. At higher temperatures there is a small peak followed by a drop, a plateau, and at the upper limit of the temperatures measured, another drop. The peak shows strong dependence on frequency. In the 0.2 Ω-cm sample, the peak is at 5.5K at 10Hz, but is shifted to 11.5K at 10kHz. This is accompanied by a shift to higher capacitance in the plateau. At 10Hz the plateau is at about 50% of the low temperature capacitance, at 10kHz, it is at 103% of the low temperature capacitance. In addition there was a much smaller peak in capacitance observed with the Andeen Hagerling bridge at 3.5K, for which we have no explanation.

The amplitude of the loss at temperatures above about 5K is highly dependent on frequency, the peak loss being roughly proportional to frequency. Direct comparison between the loss at the various frequencies is thus difficult. However, if the loss is normalized, various features are seen to be consistent across all orders of frequency measured. At low temperature, the loss is negligible. As the temperature increases, there is a peak, which depends in a similar way on frequency to the peak observed in the capacitance. Then the loss falls rapidly, becoming large and negative. Higher temperature measurements show the loss eventually returns to zero. Most of the interesting features occur below 20K.

SSDI 0921-4526(93)E1120-B

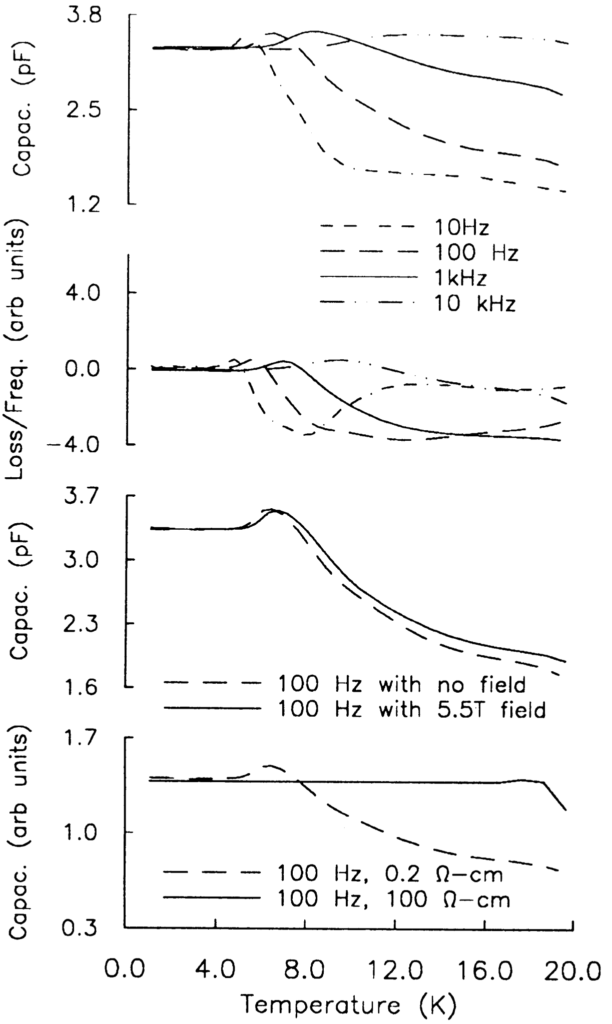

Figure 1. Capacitance of Boron Doped Silicon.

Measurements were also made on the 0.2 Ω-cm sample in a magnetic field of 5.5T. A shift of less than a degree toward higher temperature was observed in the capacitance and loss peaks.

A comparison of the 0.2 Ω-cm and 100 Ω-cm samples shows that the 100Ω-cm sample exhibits behavior similar to the 0.2 Ω-cm sample. However, the initial peak in the capacitance and loss are shifted to a higher temperature, about 18K and about 17K respectively, at 100Hz. Both samples enter a regime of slowly varying capacitance and loss at about 22K.

We note that the data do not resemble the prediction for the case of a metal insulator transition in a dielectric between the plates of a capacitor. For such a case, one expects a constant capacitance when the dielectric is non-conducting. When the dielectric becomes conducting, it should act as a region where the electric field goes to zero. This would increase the capacitance. A smooth transition is expected between these regions. However, in our configuration we also have a large capacitative coupling between the sample and ground. The features observed are consistent with a model in which the increasing dielectric constant of the silicon is competing with the increasing capacitative coupling to ground due to the falling resistance of the silicon.

4. CONCLUSION

Capacitative measurements have been made of highly doped silicon at low temperatures. Features were observe which change as a function of temperature, doping, and magnetic field, and which are consistent with the metal insulator transition. We plan to extend measurements to lower temperature and different doping levels.

5. ACKNOWLEDGEMENTS

This research was supported by National Science Foundation under DMR91-23857 and DMR91-21654.

REFERENCES

1. K. V. Rao and A. Smakula, J. Appl. Phys. **37**, 2840 (1966)
2. A. Smakula et al, J. Appl. Phys. **43**, 508 (1972).