ELSEVIER

Nuclear Instruments and Methods in Physics Research A 370 (1996) 147-149

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Experimental studies of amplification using evaporation and adsorption of helium

T. More, J.S. Adams, S.R. Bandler[1], S.M. Brouër[2], R.E. Lanou, H.J. Maris, G.M. Seidel*

Department of Physics, Brown University, Providence, RI 02912 USA

Abstract

The design of a phonon amplifier based on the evaporation of helium atoms from a superfluid film and their adsorption onto a bare solid surface is discussed. Experimental results indicate that substantial improvement in efficiency is required to be able to construct such an amplifier. A possible modification to achieve this improvement is considered.

In an effort to make possible the measurement of low-energy, nuclear-recoil events in a large mass, dark-matter detector at low temperature, we have investigated the possibility of constructing a phonon amplifier based on the evaporation and adsorption of helium atoms. The design of the amplifier is shown schematically in Fig. 1. The detector, a high quality single crystal, is covered with a superfluid helium film below 0.1 K where the vapor pressure of helium is negligibly small. Phonons created by a nuclear recoil propagate to the surface where they generate excitations in the liquid helium film. These excitations, if they have an energy greater than the binding energy of a helium atom to the liquid of 7 K, have some probability of desorbing helium atoms. The desorbed atoms hit, and are likely to stick to, wafers that surround the target crystal. Each wafer is maintained free of helium on the surface facing the detector and covered with superfluid helium film on the opposite side [1]. When a helium atom is adsorbed on a bare surface, the energy deposited in the wafer is principally the binding energy and is typically the order of 100 K [2]. Within the wafer this energy will propagate as one or more phonons, and upon reaching the opposite film-covered side, can create excitations in the film. These excitations, in turn, can evaporate other helium atoms. Because of the large difference in binding of a helium atom to the liquid and to the bare solid surface, it is possible energetically to evaporate several atoms for each incident atom. This process of adsorption and evaporation can be repeated on a number of wafers each bare on one side and helium-covered on the other. A bolometer is attached to the final wafer, bare on both sides, to measure the energy deposition. Provided that the gain per stage (wafer) is greater than one, i.e. more atoms are evaporated at each stage than are adsorbed, a proportional amplifier can be constructed [3].

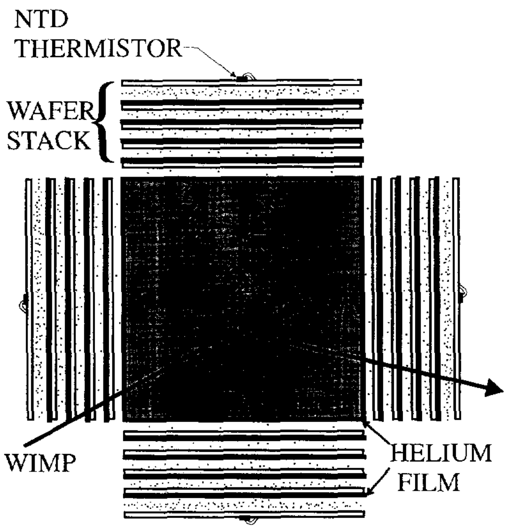

Fig. 1. Schematic diagram of amplifier. A dark matter target crystal is covered with a superfluid helium film. The crystal is surrounded by sets of wafers, each of which is free of helium on the side facing the target and covered with helium film on the opposite side. The outermost wafers are completely free of helium and have thermistors attached.

* Corresponding author. Tel. +1 401 863 2584, fax +1 401 863 2024, e-mail seidel@physics.brown.edu.

[1] Present address: Universität Heidelberg, Heidelberg, Germany.

[2] Present address: Universität Karlsruhe, Karlsruhe, Germany.

Elsevier Science B.V.
SSDI 0168-9002(95)01118-8

In addition to the ratio of the binding energies, the gain of the amplifier depends on a number of processes, some of which can result in significant energy losses. (1) Some phonons generated by the nuclear recoil in the target crystal or by adsorption in a wafer stage may have energies less than the 7 K required for evaporation of helium. (2) High energy phonons can down-convert to phonons with energies below 7 K. (3) The transmission probability of phonons across the solid–liquid interface is less than unity. (4) In the liquid film, elementary excitations can down-convert to energies less than 7 K. (5) Because of kinematic constraints some excitations with sufficient energy cannot cause quantum evaporation. (6) The probability of evaporation by events that are kinematically allowed is less than unity. (7) The sticking probability of a helium atom hitting a bare solid surface is less than one.

We have made an experimental study [4] of the energy deposited by adsorbed helium atoms on bare silicon and sapphire wafers as a result of an alpha particle being stopped in a target crystal covered with a helium film. By varying a number of parameters we are able to investigate the processes that are involved in the performance of an amplifier based on the evaporation and adsorption of helium. The experiment most relevant to this discussion is illustrated schematically in Fig. 2. A silicon target crystal forms one side of a vacuum cell, the vacuum seal to it being formed by an indium "O" ring. Alpha particles from an ^{241}Am source are incident on the target from the vacuum side. Above the opposite side of the target, which is covered with a saturated helium film, is suspended a film-free collection wafer with an attached NTD germanium thermistor. The 5.5 MeV alpha particles from a second movable ^{241}Am source are used to calibrate the response of the collection wafer.

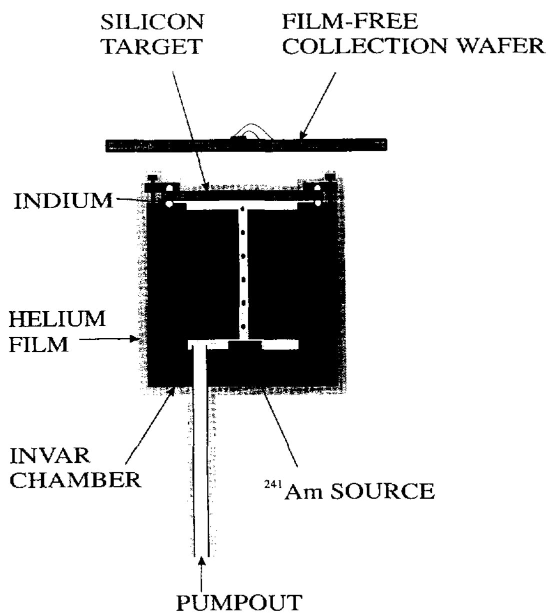

Fig. 2. A silicon target crystal is sealed to a vacuum chamber using an indium "O" ring. The outer surface of the target is covered with a superfluid film. A collimated alpha source (^{241}Am) is placed inside the chamber and a film-free collection wafer with thermistor attached is directly above the target. A second alpha source can be moved so that alpha particles can strike the collection wafer directly.

The measured energy input to the collection wafer resulting from helium atoms evaporated by an alpha particle striking the target is 1.0 MeV. Thus the gain per stage measured under the conditions of this experiment is considerably less than the value of unity needed for constructing an amplifier. In a series of other experiments [4] we have determined that the principal mechanisms responsible for the energy loss are a combination of (3) through (6) on the list above. We are not aware, at the present time, of any changes in materials or surface conditions that are likely to improve the evaporation from a superfluid film to the extent necessary to make feasible a practical amplifier based on the design discussed above.

There is, however, another means by which the performance might be dramatically enhanced. The saturated film of superfluid can be replaced by a monolayer of weakly adsorbed helium atoms on an alkali metal surface. Energy losses in the liquid helium film appear to be an important reason why the energy measured at the collection wafer in the present experiment is much less than the initial energy of the alpha particle. The efficiency with which phonons desorb weakly-bound helium atoms from a monolayer may be much greater than the efficiency for creation of excitations in a helium film and the subsequent evaporation of atoms by those excitations. Helium is very weakly bound to the alkali metals. Although liquid helium does not wet a cesium surface at low temperatures [1], helium atoms in the first monolayer on cesium are expected to be bound with an energy of 1 to 3 K [5]. Only a few layers of cesium are required to achieve this low binding. The target crystal can be coated with cesium and then a monolayer of helium added. We intend to explore this approach.

Acknowledgements

This work was supported by the U.S. Department of Energy under grant number DE-FG02-88ER40452 and by the National Science Foundation through the Center for Particle Astrophysics at the University of California, Berkeley. T. More acknowledges additional support from the U.S. Department of Education.

References

[1] The discovery that liquid helium does not wet a surface of cesium makes the construction of a wafer with helium only on one side a practical possibility. See E. Cheng, M.W. Cole, J. Dupont-Roc, W.F. Saam and J. Treiner, Rev. Mod. Phys. 65 (1993) 557 for a review.

[2] The adsorption energy of helium on a number of surfaces has been reviewed by G. Vidali, G. Ihm, H.-Y. Kim and M.W. Cole, Surf. Sci. Rep. 12 (1991) 133.

[3] An amplifier using the evaporation of helium atoms but based on different operating principles is discussed by S. Wurdack, P. Gunzel and H. Kinder, in: Phonons 89, eds. S. Hunklinger, W. Ludwig and G. Weiss (World Scientific, New Jersey, 1989) 1394.

[4] T. More, J.S. Adams, S.R. Bandler, S.M. Brouër, R.E. Lanou, H.J. Maris and G.M. Seidel, to be published.

[5] M.W. Cole, private communication.