FACILITY FORM 602
17 (ACCESSION NUMBER) (THRU) None
(PAGES) (CODE)
TMX 56272 (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

Observation of Elastic Waves Produced by Heating From a Modulated Ion Beam

Howard F. Savage

National Aeronautics and Space Administration
Ames Research Center, Moffett Field, Calif.

In an investigation of the momentum transfer to metal surfaces from a modulated beam of energetic ions, it was discovered that the forces experienced by the surface did not occur in phase with the pulses of ions. It will be shown here that this discrepancy is due to elastic waves in the target caused by cyclic heating of the surface by the impacting particles.

In a recent publication,[1] the momentum accommodation coefficients of ions with energies between 0.5 and 4 keV incident on copper and aluminum surfaces were presented. The microbalance[2] used for that investigation did not have sufficient sensitivity to measure the variations of the momentum transfer with angle of incidence for N_2^+ ions with energies less than about 1 keV. In an attempt to extend the measurements to lower ion energies and to improve upon the accuracy of the high energy results, a new momentum transducer was developed at Ames Research Center which has greater sensitivity, is more rugged, and is more convenient to operate. A sketch of the transducer is shown in Fig. 1. The instrument operates as a spring mass system in which the target (shown mounted for normal force measurements in Fig. 1) attached to one end of the stem contains most of the mass. On the other end of the stem is one-half of a parallel plate capacitor used to produce a known force for comparison with the force due to the ion beam striking the target. The stem is attached to a pair of piezoelectric beams which serve both as springs and as acceleration sensors. This suspension provides essentially a single degree of freedom with sensitivity only in a direction along the stem. For measuring the component of momentum transfer tangent to the target surface, the target is mounted so that the tangent to the target is parallel to the stem. To get high sensitivity, advantage was taken of the resonance effect of the spring mass system. For this, the ion beam was electrically chopped at the resonant frequency (about 140 cps for a target mass of 7 g) by means of parallel deflector plates (2-1/2 × 4 cm spaced 2-1/2 cm apart) located 40 cm upstream from the target. The transit time from the deflectors to the target is then about 6 μsec for Ar^+ at an energy of 1 keV.

It was originally intended to make force measurements by applying equal forces, 180° out of phase, on each end of the stem by means of the forces due to the ion beam and the capacitor. However, it soon became evident that although the capacitor potential and the ion-beam deflector-plate potential were exactly synchronized, being taken from a common square wave generator, the forces were not synchronized and a zero output could not be obtained. It was also noted that for supposedly the same test conditions the variations in magnitude of the output due to the ion beam from one test to the next were larger by an order of magnitude than the variations expected from random instrument reading errors.

A check on the phase relations (Fig. 2) showed that for Ar^+ incident on aluminum at 1150 eV, for example, the normal force due to the ion bombardment lagged about 30° behind the expected phase with indications that the phase lag decreased with decreasing ion energy. Figure 2 was obtained by first photographing the oscilloscope trace of the amplified piezoelectric output when the driving force was the ion beam; a second trace of the output was then photographed on the same film when the driving force was produced by a square wave potential on the calibrating capacitor adjusted to give the same output amplitude as the ion beam. The oscilloscope was triggered by the common square wave generator for both traces.

It is tempting to attribute this phase lag to an actual delay in the ejection of target atoms. However, time-of-flight measurements made by Stuart, Brower, and Mayer[3] have shown no such effect. Instead, the explanation of the phase lag and scatter in the ion beam output presented herein is that elastic waves are produced by the cyclic heating of the targets. White[4] has also observed elastic waves produced by cyclic heating and has gone into the details of how they are generated and the magnitudes of the stresses involved. The output of the piezoelectric beams is then due to the momentum transferred through the target by an elastic wave which is the sum of two waves; one produced by the ion beam momentum pulses and one produced by the cyclic heating due to the ion beam pulses. The power density of the ion beam was about 0.03 W/cm^2 at an ion energy of 1 keV, corresponding to a computed[5] surface temperature rise of about

10^{-3} °C. This temperature increase in turn would induce a peak stress which is computed[5] to be in the neighborhood of 10^{-3} dynes/cm^2, as compared to a stress of about 10^{-2} dynes/cm^2 due to the force of the ion beam pulses. In order to verify that the phase lag is caused by the cyclic heating of the target, a stroboscopic lamp was used to heat the target at the resonant frequency of the transducer. The light pulse had a duration of 1 μsec and a power density of about 0.8 W/cm^2, corresponding to a temperature rise of about 0.5×10^{-3} °C. With a darkened aluminum target, the output of the transducer was of the order of magnitude of the output for the ion beam input. When a polished aluminum target was illuminated, the output was only about half that of the darkened target, indicating that the detected elastic waves were generated as a result of a rise in surface temperature since the temperature rise and resulting elastic wave would be greater for the darkened target. If the elastic waves had been due to radiation pressure, the pressure would have been greater for the polished target.

Since the peak surface temperature would occur at the end of each pulse of ions, the elastic waves caused by the heating would occur later in time than those caused by the momentum transfer from the ions to the surface. Thus, the combined peak output would be delayed and would account for the observed phase lag. Also, the variations in the magnitude of the transducer output which occurred for supposedly the same test conditions could be caused by changes in the ion beam focusing which would change the power density and thus the peak temperature rise and the resulting output due to the thermally produced elastic waves. The observed decrease in the phase lag with decreasing ion energy would be expected because of the decrease in the ion beam power density, and the resulting smaller temperature rise with decreasing energy.

[1]H. F. Savage, and M. Bader, "Momentum Accommodation of N^+, N_2^+, and A^+ Incident on Copper and Aluminum From 0.5 to 4 keV," NASA TN D-1976 (1963).

[2]V. L. Rogallo, and H. F. Savage, Rev. Sci. Instr. 34, 988 (1963).

[3]R. V. Stuart, K. Brower, and W. Mayer, Rev. Sci. Instr. 34, 425 (1963).

[4]R. M. White, J. Appl. Phys. 34, 3559 (1963).

Figure Captions

Fig. 1. Schematic diagram of the momentum transducer.

Fig. 2. Reproduction of an oscilloscope picture showing the phase relations between the piezoelectric outputs due to the ion beam force and capacitor force; Ar^+ incident on Al at 1150 eV.

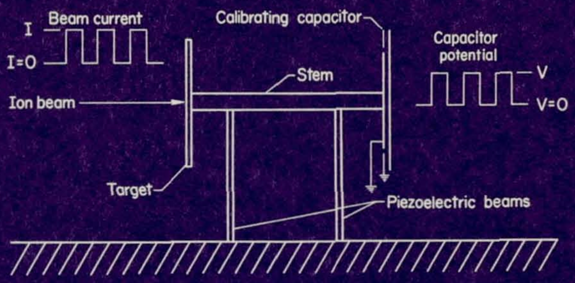

Fig. 1

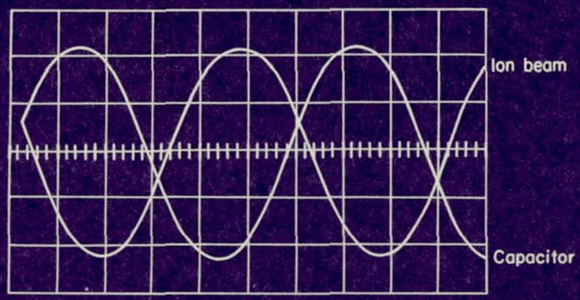

Fig. 2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA