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Homogeneously oxidized iron surfaces show modulated microwave reflections under strain. The effects are too small to account for the modulation found from actual vibrating systems, but are large compared to the response expected from clean metal surfaces. Tunneling junctions of Fe-Oxide-Fe have been investigated as a possible origin of the observed enhancement of strain sensitivity. Such tunneling junctions have been found to exist, at room temperature, but the effect found in model MOM junctions is not large enough to account for the observations.

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FINAL TECHNICAL REPORT

MICROWAVE REFLECTIONS FROM VIBRATING INHOMOGENEOUS CONDUCTING SURFACES

AFOSR Grant 76-3030
Polytechnic Institute of New York
N. J. Juretschke

This research was undertaken to assess the contribution to the modulation of electromagnetic waves reflected from vibrating conducting surfaces that could be caused by intrinsic properties of the surface. Since metal surfaces homogeneous both on the macroscopic and the microscopic level would contribute only through the strain dependence of the bulk resistivity, a very small effect at commonly encountered strain amplitudes, we have concentrated on the properties of microscopically grossly inhomogeneous metal surfaces, and in particular on the effect of weakly adhering oxides covering metal surfaces, principally oxidized iron. The program had two major directions: 1) The study of the strain sensitivity of the microwave reflectivity of actual oxidized surfaces prepared under various conditions; and 2) The study of a particular model thought likely to show enhanced strain sensitivity, namely, metal-metal oxide-metal junctions created in the surface through inhomogeneous oxidation.

The major conclusions of this study are:

A) Real metal surfaces covered with rough oxides, such as rusty iron, show a strain sensitivity of microwave surface resistance up to about a factor 30 larger than expected for pure metal surfaces. Within our limits of detectability, the experimental data on pure iron and other metals showed no observable strain response.

B) This enhanced sensitivity is a delicate function of the properties of the substrate, i.e. impurity content of the iron and degree of cleanliness of the surface before oxidation, and of the specifics of the oxidation process, e.g. temperature, moisture and CO_2 content, etc. As a result we found that one cannot predict or anticipate the response of any naturally weathered surface. We have not been able to correlate the sensitivity with any particular oxide or oxide combinations. The factor of 30 mentioned in A) is the maximum reached by us, although more often the response is smaller.

C) The maximum factor of 30, while large, will still only alter the reflection coefficient of microwaves by about 10^{-3} , far too small to account for the magnitudes of observed signals from vibrating structures.

D) A consistent interpretation of the microwave data requires that the surface layer be described by a conductivity lower by 10^{-2} than that of bulk iron, and that the strain sensitivity of this conductivity is enhanced by a factor of 10^3 above that of normal bulk metals. The maximum observable effects occur when the surface layer thickness is less than the skin depth of material in the surface layer.

E) It is plausible to identify the observed surface layer resistivity with that of Fe_3O_4 . However, our experiments on highly oxidized thin layers of iron did not show any anomalously large effect in the strain sensitivity of its resistivity, as long as the oxide is uniform.

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F) As a possible contributor to the observed large strain sensitivity we have explored the electrical properties of microscopic inhomogeneities, such as thin oxidized layers between conducting material, in terms of a model structure of a thin metal film with a fine line constriction across its width that could be oxidized to completion. We have found that such thin-line junctions can be strongly non-ohmic at room temperature. The nonlinear characteristics follow those expected for tunneling across an insulating barrier. Considering that the barrier may be as thick as 10^{-3} cm, the junctions show relatively low resistance.

G) As to be expected for tunneling junctions, the strain sensitivity of the junction resistance is enhanced, and we have measured increases of about a factor 10 above that for pure metals. Such a factor falls far short of that needed to account for the changes observed in D). It was not possible to identify the specific oxides forming the junction barrier, and the difference between the thin film results and the macroscopic measurements may arise from the fact that in thicker oxides the predominant barrier occurs as FeO between grains of Fe_3O_4 , rather than oxide between metal.

H) The losses accompanying the closing of an air gap with rusty surfaces were studied in an equivalent wave guide structure, and showed qualitatively that the insertion loss varies continuously as the gap is closed and the surfaces make contact. This behavior was also confirmed by calculations of the scattering cross section of a slit containing an imperfect conductor.

As a result of these studies we conclude that the strain sensitivity intrinsic to microscopically inhomogeneous surfaces that are macroscopically continuous, while showing considerable enhancement above that of bulk metals, is insufficient to account for the large modulation signals observed from vibrating structures. In the course of our experimentation we confirmed that macroscopic contact effects are orders of magnitude larger unless very special precautions are taken, and calculations show that modulation from macroscopic gaps can indeed give signals of the proper magnitude.

A listing of internal reports and memoranda generated during the course of this work is attached. An article entitled "Elastoresistivity of Thin Line MOM Junctions" is being prepared for publication.

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Internal Reports and Memoranda

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Scattering by a slit in a finite plate and its application to
the RADAM problem

A. Hessel and J. Shmoys

Strain dependence of rust layers at X-band

H. L. Bertoni and L. M. Silber

Elastoresistance and electron tunneling in oxidized iron

T. Pignataro and M. Eschwei

Surface resistance of a two layer surface, comparison of experiment
and theory

L. M. Silber

Resistance of thin-line Fe-Oxide-Fe junctions as a function
of oxide thickness

L. Amani, M. Eschwei and H. J. Juretschke

Strain dependence of rust layers at X-band - corrections for
contact effects

H. L. Bertoni and L. M. Silber

Elastoresistivity of thin-line MOM junctions

H. J. Juretschke and M. Eschwei

Radar cross section for thin slits filled with an imperfect
conductor

H. L. Bertoni