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# Metallic Glass as a Temperature Sensor During Ion Plating

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TEMPERATURE SENSOR DURING ION PLATING (NASA)  
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# METALLIC GLASS AS A TEMPERATURE SENSOR DURING ION PLATING

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## SUMMARY

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An investigation was conducted to examine the temperature of the interface and/or of a surficial layer of a substrate during ion plating. A metallic glass of the composition  $Fe_{67}Co_{18}B_{14}Si_1$  was used as a substrate and as the temperature sensor. Transmission electron microscopy and diffraction studies were also conducted to determine the microstructure of the ion-plated gold film and the substrate. The results of this investigation indicate that crystallization occurred not only in the film, but also in the substrate. The grain size of crystals formed during ion plating was 6 to 60 nm in the gold film and 8 to 100 nm in the substrate at a depth of 10 to 15  $\mu m$  from the ion-plated interface. The temperature rise of the substrate during ion plating was approximately 500° C. Discontinuous changes in metallurgical microstructure, and physical, chemical, and mechanical properties during the amorphous to crystalline transition in metallic glasses make metallic glasses extremely useful materials for temperature sensor applications in coating processes such as ion plating.

## INTRODUCTION

The present authors have investigated the composition profiles of graded interfaces by X-ray photoelectron spectroscopy (XPS) depth profiling and microhardness depth profiling in order to understand the reaction mechanism for adhesion and interfacial formation and to improve tribological properties of thin ion-plated films (refs. 1 and 2).

When gold is ion plated onto nickel and iron, a graded interface forms. The interface for nickel is deeper than the one for iron. The solubility of material pairs controls the depth of the graded interface between the film and the substrate. With gold and nickel the graded interface can be an alloy of the metals. Both thermal and chemical diffusion may be the mechanisms of the formation of the interface. With gold and iron the gold in the graded interface with iron is primarily atomically dispersed in the iron and thus forms a physically bonded interface (refs. 1 and 2).

In addition to knowing the composition and its variation in the film and at the film and substrate interface, it is important to know the temperature at the interface, or the surficial temperature of the substrate during ion plating, or both. The high energy flux to the substrate causes high surface temperatures, which enhance the diffusion and the chemical reaction of the plating material with the substrate (ref. 3).

It is useful to quantify the substrate heating in terms of the energy delivered to a surface. With this information it is possible to estimate the

temperature that a given substrate will reach while depositing a particular coating. For example, at a moderate deposition rate (several hundred Å/min) substrate temperatures can reach 300° to 500° C (ref. 4). However, a direct measurement of the interface temperature and/or surficial temperature of the substrate would be more meaningful.

The present investigation was conducted to examine the temperature of interface and/or of the surficial layer of the substrate during ion plating. A metallic glass (amorphous alloy of the composition Fe<sub>67</sub>Co<sub>18</sub>B<sub>14</sub>Si<sub>1</sub>) was used as a substrate and as a temperature sensor. Ion plating was conducted for 15 sec with a negative potential of 3.5 kV and a substrate current density of 0.5 mA cm<sup>-2</sup> in argon at a pressure of 0.27 Pa (20 mtorr). Transmission electron microscopy and diffraction studies were used to determine microstructures of the metallic glass.

## MATERIALS

Gold with a purity of 99.99 percent was the plating material. The substrate specimen was a metallic glass (amorphous alloy) whose composition and general properties are given in table I. The metallic glass was in the form of a ribbon (0.030 to 0.033-mm-thick foil) and was used in the as-cast condition.

## APPARATUS

The ion-plating chambers used in this study have been described elsewhere (ref. 2). The chamber is evacuated by a mechanical and diffusion pumping system and a liquid-nitrogen trap. An alternative pumping system was also used to eliminate any possible external contamination, such as oil backstreaming during the pumping cycle. The mechanical and diffusion pumps were isolated from the chamber, and the pumping was performed directly by two vacuum absorption pumps.

## EXPERIMENTAL PROCEDURE

The specimen to be ion plated is the cathode of a high-voltage, dc circuit, and the resistance-heated tungsten evaporation boat is the anode. The plating conditions used during this study are those most commonly used in commercial ion plating. A negative potential of 3.5 kV was applied to the specimen, with a substrate current density of 0.5 mA cm<sup>-2</sup> at an argon pressure of 0.27 Pa (20 mtorr) for 15 sec. The specimen-to-boat distance was 10 cm. Before evaporation, the substrate was dc sputter cleaned for 15 min at 1 kV, at 15 mA, and at an argon pressure of 0.27 Pa (20 mtorr). The coating thickness of gold on the substrate was 0.18 μm.

Specimens were thinned for transmission electron microscopy and diffraction studies by ion-etching and electropolishing. To examine the microstructure of the metallic glass foils, they were heat treated in a vacuum of 30 nPa to a maximum temperature of 750° C for 20 to 30 min. The foil was resistance heated, and its temperature was measured with a contacting thermocouple.

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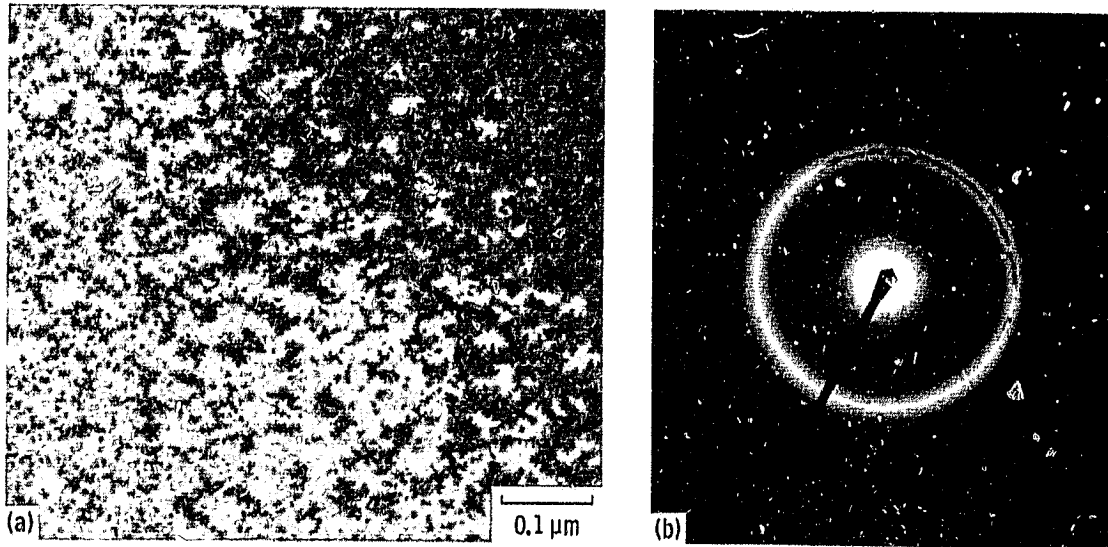


Fig. 1. As-received metallic glass: (a) microstructure and (b) diffraction pattern.

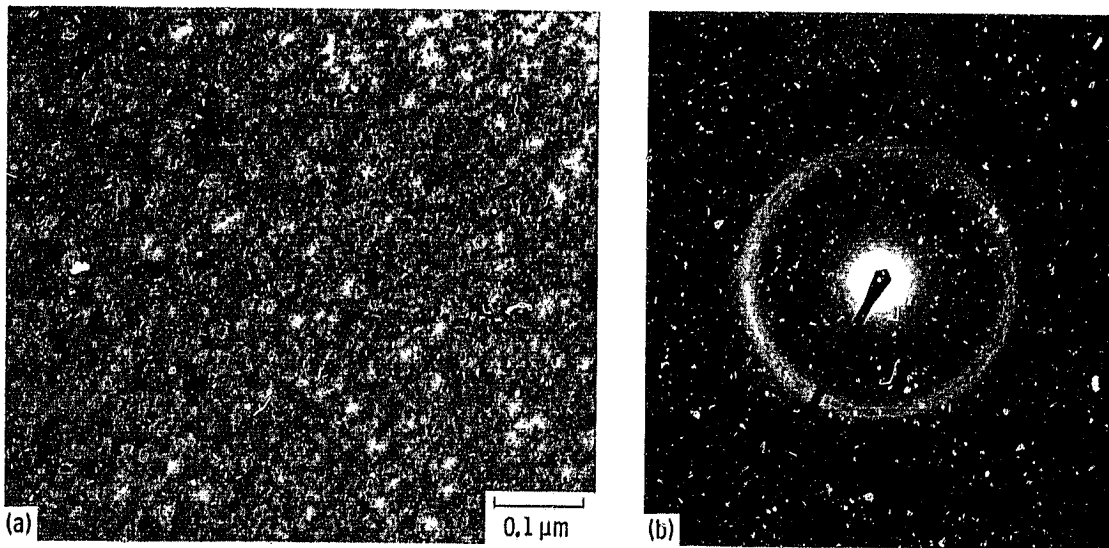


Fig. 2. Metallic glass heated to 350<sup>o</sup> C: (a) microstructure and (b) diffraction pattern.

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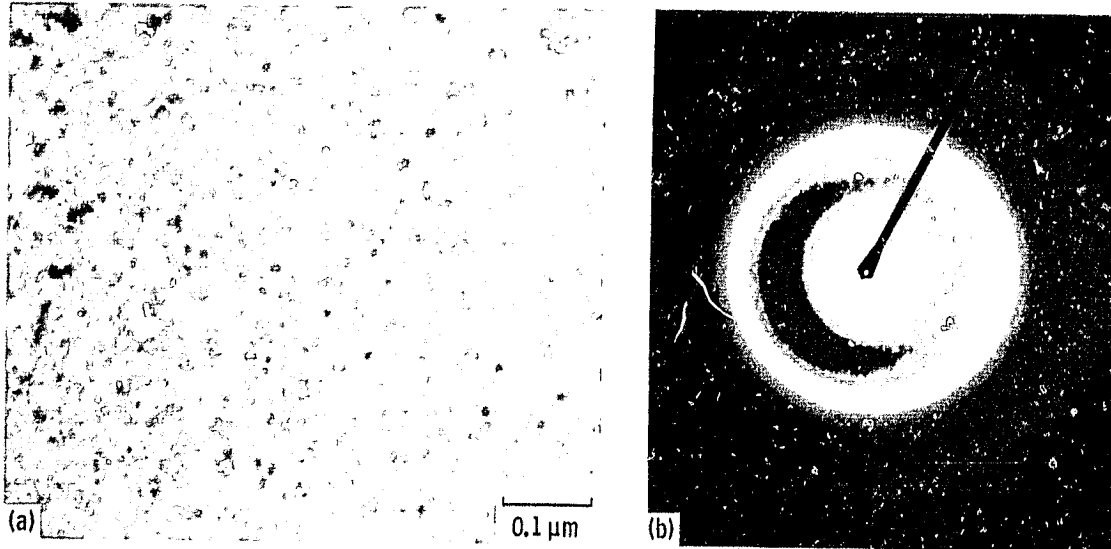


Fig. 3. Metallic glass heated to 430<sup>o</sup> C: (a) microstructure and (b) diffraction pattern.

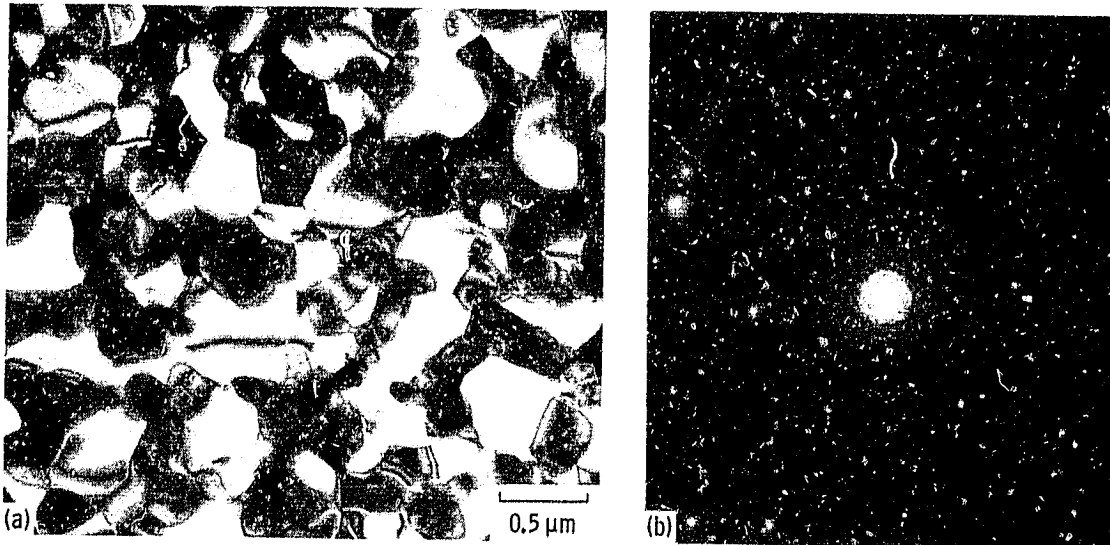


Fig. 4. Metallic glass heated to 500<sup>o</sup> C: (a) microstructure and (b) diffraction pattern.

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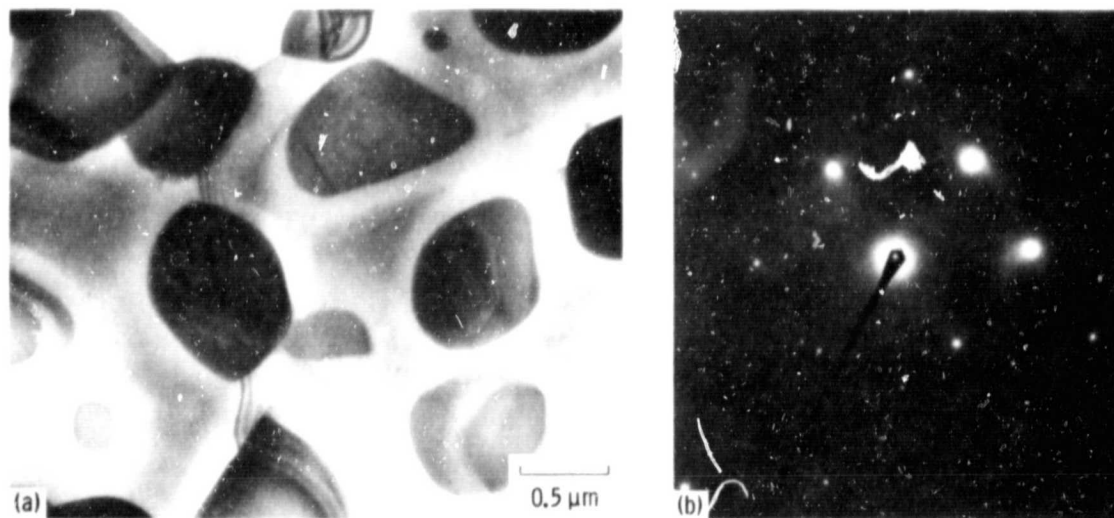


Fig. 5. Metallic glass heated to 750<sup>o</sup> C: (a) microstructure and (b) diffraction pattern.

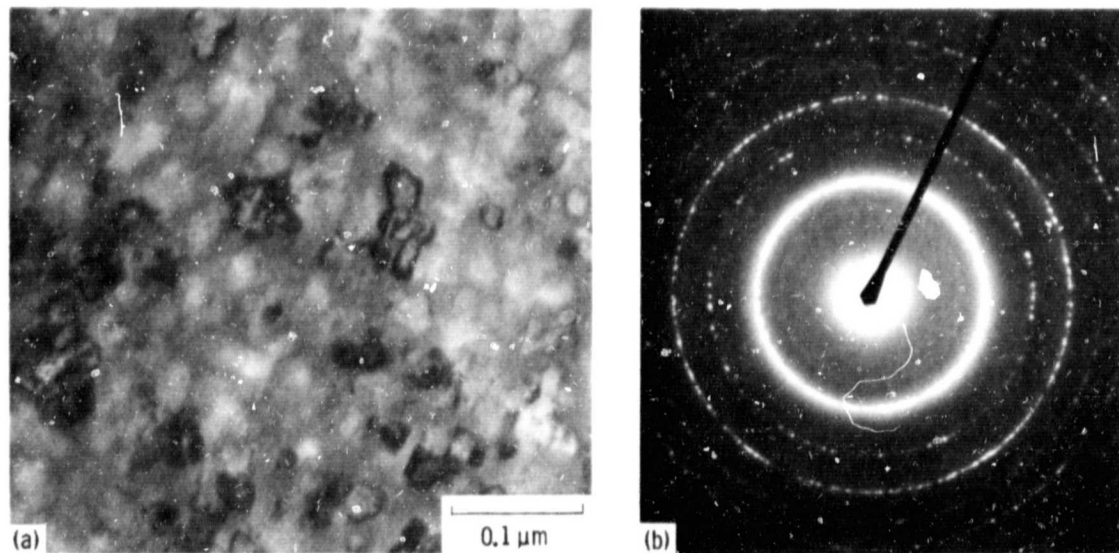


Fig. 6. Metallic glass substrate showing crystallites generated during ion plating: (a) microstructure and (b) diffraction pattern.

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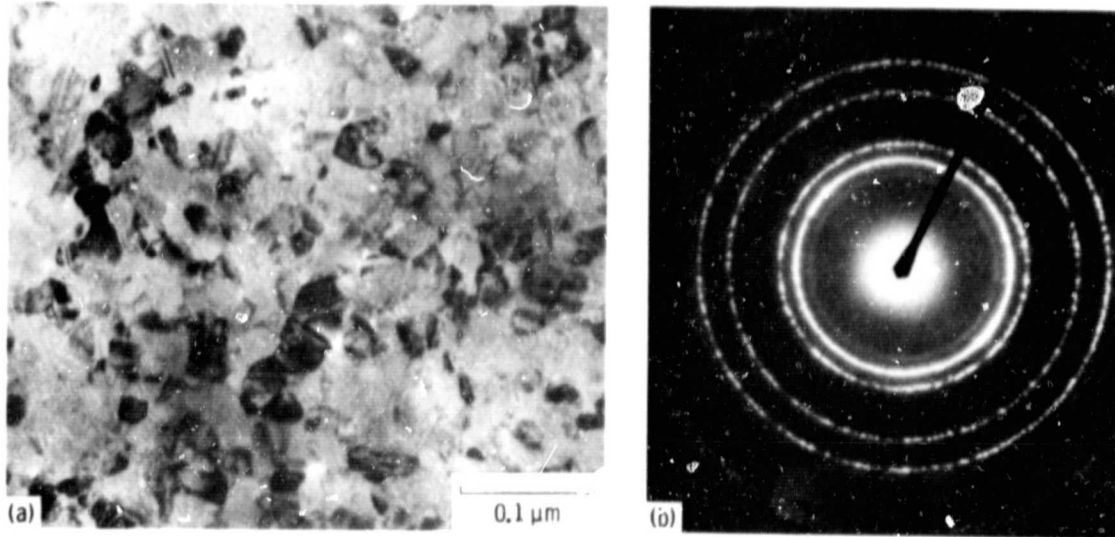


Fig. 7. Ion-plated gold film showing crystallites generated during ion plating: (a) microstructure and (b) diffraction pattern.

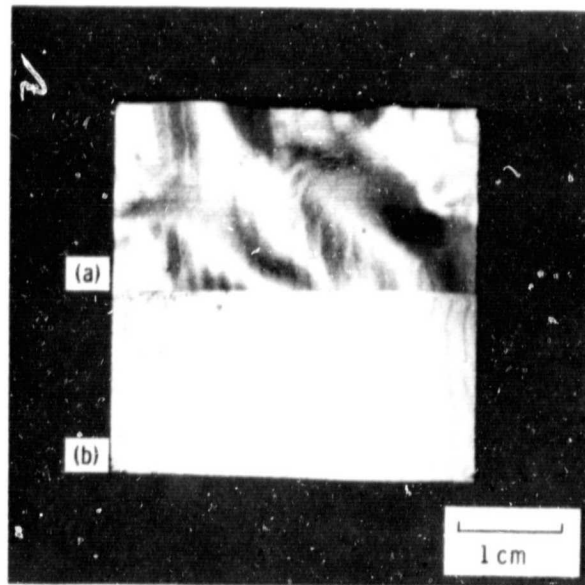


Fig. 8. Photographs of (a) ion-plated gold film on a metallic glass substrate and (b) as-received metallic glass.