Stress Reduction in Metallization using in-situ Stress Measurement and Plasma Assisted Evaporation

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Abstract

Nickel layers were deposited by e-beam evaporation using plasma assistance. The stress in the layers was investigated by using in-situ stress measurement. A Design Of Experiments (DOE) using different deposition parameters allowed us to identify conditions resulting in layers with low stress. The optimized stress value is considerably lower than the values, which can be obtained by evaporation without plasma assist and which were obtained so far in the standard process. Additionally, the investigations showed that development time can be reduced strongly by using in-situ stress measurement, because venting between individual tests is not necessary.

INTRODUCTION

Stress plays an important role in metallization layers. The adverse effects of excessive stress are manifold and range from adhesion problems to thin wafer bending and fatigue effects. It is thus an important task to reduce stress. To assess stress, bending of a substrate is often measured before and after coating. These measurements show the total stress of a metallization, but not the stress of the individual layers of which a metallization may consist. Thus, in-situ measurements allow us to observe the contribution of stress in the individual materials and the evolution of stress depending on different deposition parameters. In addition, the traditional way of measuring stress has the disadvantage that only one deposition condition can be tested at a time; then the coating chamber has to be vented. This series of experiments confirmed, that by using in-situ stress measurement the development time can be reduced strongly, since a series of experiments can be done in one single coating batch. For a specific application we performed a DOE to investigate and optimize stress in Nickel layers by using plasma assisted deposition. The investigations showed that plasma assist indeed can reduce stress in Nickel layers by approximately 50% and the DOE let us identify the optimum deposition parameters.

EXPERIMENTAL

The metal films were deposited by electron beam evaporation using an Evatec box coater, BAK 1101, which is equipped with an Evatec IS300 ion source, as shown in Figure 1. For the present test this source was used to produce a high density Argon plasma with mean ion energies in the range of 35 – 250 eV.

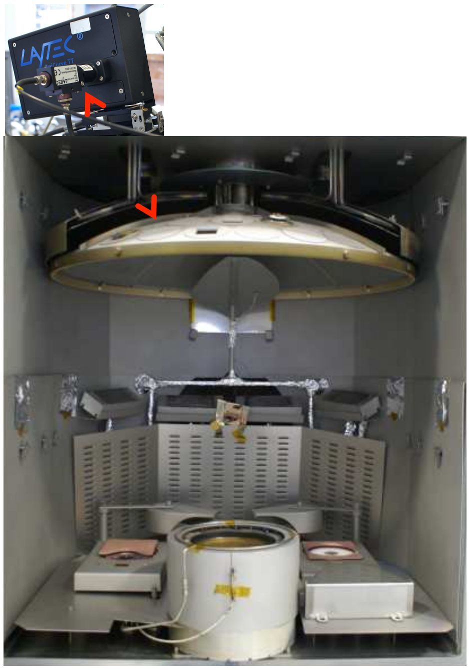

FIGURE I: BAK 1101 Box coater configured with in-situ stress measurement head EpicureTT and ion source IS300

For the in-situ stress measurement LayTec adapted their Epicurve [1] senor head such that it is capable of measuring a witness sample placed on the rotating dome shaped substrate holder. The sensor head is mounted on top of the vacuum chamber and measures the sample from the backside. In this non-contact measurement two parallel laser beams are reflected from the witness sample and the detector determines the radius of curvature from the distance of the two reflected beams. The stress can then be calculated by taking into account the material and thickness of the substrate as well as the thickness of the film.

For the deposition experiments a full factorial DOE with the three parameters deposition rate, Ar gas flow and ion energy was chosen (see Tab. I). Based on preliminary tests these parameters were identified to have the biggest impact on stress.

2 inch double side polished Silicon witness samples with a thickness of 275 µm were used to enable the stress measurement form the back-side. The deposition runs always started with Ti/Al, which are the starting layers of the stack. It is known that the sub-layers influence the stress of the Nickel layer as compared to direct deposition of the Nickel on Silicon.

In the experiments described here two parameter settings of nickel, each with a thickness of 300 nm, were deposited one after the other on top of the Ti/Al layers without venting. In retrospective it would have been even more favorable to deposit 3 settings at a thickness of 200 nm without venting.

TABLE I: PARAMETERS OF THE FULL FACTORIAL DOE

		low	high
Ar Flow	[a.u.]	25	50
Deposition Rate	[a.u.]	0.8	1.8
Ion Energy	[a.u.]	100	900

RESULTS

As mentioned in the introduction, in-situ stress measurements enable to determine the stress, which evolves in each of the different layers of the stack. As can be seen in Figure 2, the Ti and Al layers show compressive stress equivalent to -316 and -46 MPa respectively. The two parameter combinations of Ni were run one after each other and show 1072 and 920 MPa of stress.

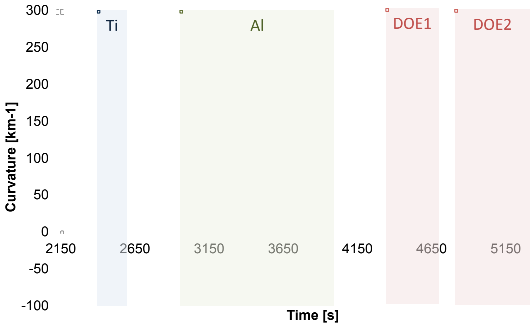

FIGURE 2: Evolution of stress in a Ti/Al / Ni coating

As detailed earlier a full factorial DOE was deposited except for the combination - - +. These experiments yielded stress values ranging from 700 to 1400 MPa.

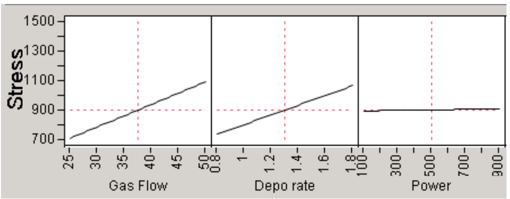

FIGURE 3: Evaluation of DOE by JMP

The values obtained were evaluated using the statistical software JMP and can be seen in Figure 3. The evaluation of the data shows that low stress is obtained for low gas flow and deposition rate, whereas the influence of ion energy (labeled as power) is small.

Based on these results the parameter range was extended towards low stress values. The parameter, which could be changed the most was the deposition rate. Indeed, the stress in the deposition run with low rate was reduced to a value of 276 MPa.

At this point the question was left open, whether the stress could be reduced with lower deposition rate also without the use of plasma assist. To clarify this question two additional runs were coated with and without the use of the plasma source, this time with the full thickness of Nickel in the stack. Nickel with plasma source evolves now somewhat higher stress than in the thin pre-tests, because of the initial phase with compressive stress has a lower fraction of the coating. Nevertheless, the stack with plasma source shows again lower stress of 494 MPa as compared to 822 MPa without plasma assist, as can be seen in Figure 4:

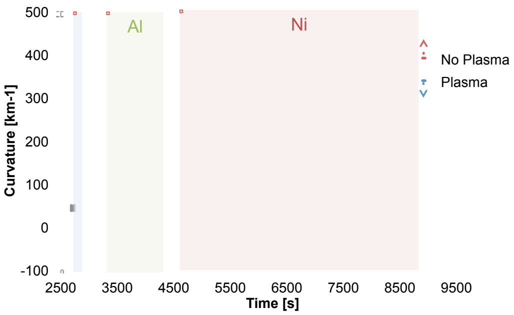

FIGURE 4: Stress in Nickel layer with and without plasma assist

CONCLUSIONS

The investigations have led to the following insights and results:

- proof of feasibility of in-situ stress measurements on a rotating dome shaped calotte
- Reduction of film stress in Nickel by performing a DOE
- Showed that the reduction in stress is due to the use of an ion-assisted process
- Considerable time saving by using in-situ stress measurements, which do not require venting after each parameter setting

REFERENCE

1 EpiCurve TT, Laytec AG, Seesener Str. 10-13, 10790 Berlin, Germany

ACRONYMS

DOE: Design of Experiment