ELECTRO-THERMAL DEFORMATION MEASUREMENT OF MICRO FILM LINE ON POLYMER MEMBRANE BY GEOMETRIC PHASE ANALYSIS

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Summary The electro-thermal deformation of a constantan film line on a polymer membrane is measured by geometric phase analysis under a 3D super depth digital microscope. The displacement and the strain fields of the constantan line at different electrifying times are obtained. There is tensile strain in the constantan line, which rises rapidly at the beginning of electrification and then drops with increasing electrifying time. This work offers an effective in situ technique for measuring the micro deformation of film lines induced by electricity.

INTRODUCTION

Structures of film lines and polymer substrates are extensively employed in integrated circuits and micro electromechanical systems with the development of flexible electronics [1]. Since the deformation of film lines directly affects the stability and reliability of the structure, it is of great importance to measure the electro-thermal deformation of film lines under electrical loading. As the size of film lines has reduced to submicron levels, a micro/nano-deformation measurement method should be used. Optical measuring techniques provide effective ways to acquire the micro deformation due to their non-contact nature. The moiré method provides high resolution, but the moiré pattern processing is intricate. The digital image correlation method is simple to perform, however, a high quality micro speckle is hard to fabricate. Electronic speckle pattern interferometry, a useful full-field technique, is limited by the complicated experimental set-up and procedure. Owing to high accuracy and automatic processing, geometric phase analysis (GPA) attracts our attention in the current work. Since first proposed in 1998 [2], GPA has been developed into a mature approach to measure the deformation of periodic structures. The corresponding commercial software has been put into use and the highest resolution can reach 0.003 nm [3]. In this paper, the electro-thermal deformation of a constantan film line on a polymer membrane under electrical loading has been studied.

SAMPLE AND EXPERIMENT

Sample preparation

The sample formed by a constantan film line and a polymer membrane is fabricated through lithography. The constantan film line containing 55% copper and 45% nickel is distributed in the shape of a narrow 'S'. The polymer membrane is composed of 90% polyvinyl formal-acetal and 10% epoxy novolac. The geometrical dimensions of the sample can be determined by a 3D super depth digital microscope (KEYENCE VHX-500FE). The width and the thickness of the constantan line are 26 μm and 6 μm, respectively. The spacing between two adjacent parallel segments and the length of one parallel segment of the constantan line are 80 μm and 3.1 mm, respectively. The length, the width and the thickness of the polymer membrane are 7 mm, 5 mm and 60 μm, respectively.

Grating fabrication and electrification experiment

A cross-grating with a frequency of 1000 lines/mm was chosen to be fabricated on a selected constantan line in the central region of the sample. Fig. 1a displays the SEM image of the grating fabricated in a focused ion-beam (FIB) system. When the grating is milled, the accelerating voltage of the ion beam is 30 kV. The width and the length of the grating region are 26 μm and 80 μm, respectively. The depth of the grating is set to be 0.3 μm, far thinner than the thickness of the constant line. So the influence of the grating on the constantan line can be neglected.

Before the electrification experiment, the glass transition temperature of the polymer membrane was measured to be 120.09 ^{o}C, determined by a differential scanning calorimeter (DSC-60). During the electrification process, the sample temperature was measured by a thermal infrared imager (ThermaCAM P60). Since flexible electronics are usually affixed on a rigid plate to avoid crimping of the soft substrate, the four sides of the sample are adhered to organic glass. The electrification experiment is performed at room temperature. The constantan line is electrified in a simple closed circuit, including a power supply, an ammeter, a resistor, and a switch, where the power supply provides an alternating current (AC) with a frequency of 50 Hz. In the range of operating current densities, 1.92×10^{8} A/m^{2} is chosen to be the applied current density. At different electrifying times, the grating topographies on the constantan line are recorded under the 3D super depth digital microscope mentioned above.

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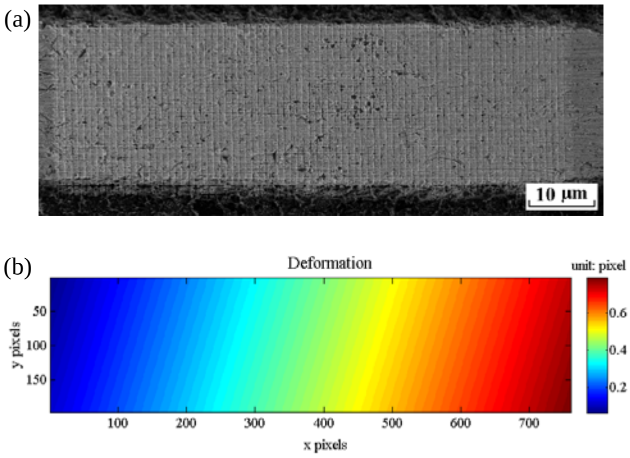

Fig. 1 (a) SEM image of the grating with a frequency of 1000 lines/mm on a constantan film line. (b) Longitudinal displacement field of the constantan line after bearing 1.92×10^8 A/m^2 AC for 5 min (0.06 μm per pixel).

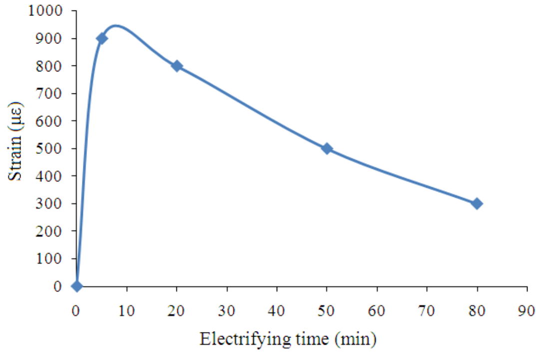

Fig. 2 Longitudinal strains of the constantan line after bearing 1.92×10^8 A/m^2 AC with different electrifying times.

RESULTS AND DISCUSSIONS

The measured temperature was 32.7 ^{o}C for the current density of 1.92×10^8 A/m^2. As this temperature is much lower than the measured glass transition temperature (120.09 ^{o}C), the glass transition of the polymer membrane did not occur. Since only the longitudinal deformation of the film line is normally of interest, only the longitudinal displacement and the strain of the constantan line relative to the original state before electrification is calculated by GPA. The computational formulas can be seen from Ref. [4]. Fig. 1b exhibits the displacement field taking the grating image after the constantan line has been subjected to this electric current for 5 min as an example. The mean strain of the constantan line at this time is 900 με.

The longitudinal strains of the constantan line after bearing the current density of 1.92×10^8 A/m^2 for 5 min, 20 min, 50 min and 80 min are plotted in Fig. 2. It can be seen that the electro-thermal strain is tensile and rises rapidly at the beginning of electrification. Then the tensile strain decreases gradually with increase of the electrifying time. This phenomenon is related to the temperature variation of the sample after the constantan line is electrified. After electrification, the sample temperature grows rapidly and almost keeps constant soon. The tensile strain comes from the thermal expansion of the sample due to the Joule heating. As the thermal expansion coefficients of the constantan line (α_c=14.9×10^{-6} /K) and the polymer membrane (α_p=70×10^{-6} /K) are much larger than that of the organic glass (α_g =0.55×10^{-6} /K), the positions of the four sides of the sample are determined by the organic glass and compressive stresses exist both in the constantan line and the polymer membrane.

With the increase of the electrifying time, the sample temperature almost remains the same and the sample will not continue to expand. Under the inner compressive stresses in the constantan line and the polymer membrane, the sample will contract a little and thus the tensile strain of the sample drops with the time. From the value of the tensile strain in Fig. 2, the maximum strain is less than 1000 με and the tensile strain will fall below 300 με after an electrifying time of more than 80 min. It indicates that the sample can work for a long time under this current density.

CONCLUSIONS

The electro-thermal deformation of a constantan film line on a polymer membrane under electrical loading has been investigated by the geometric phase analysis technique. A cross-grating was fabricated on the constantan line using the focused ion-beam milling technique. The longitudinal electro-thermal strain is tensile, rises rapidly at the beginning of electrification and then decreases gradually with increasing electrifying time, for which the reason is discussed. GPA combined with a 3D super depth digital microscope is effective in measuring the in situ micro deformation of film lines under electrical loading.

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