Biomimetic Surface Composite Effects Achieved by Interfering Laser Beams

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ABSTRACT

The composite effect means that the performance of the material is strongly enhanced by combination of materials with different properties in a well-defined manner. These observations from natural insects and trees have invoke the construction of such materials. One prominent characteristics is their micro/nano scaled periodicity. Laser interference process has been employed to produce such periodic structures on thin film systems in order to achieve these composite effect. In this work, a series of examples have been displayed to show how the surface composite can be produced by laser interference process. Under suitable laser interference conditions, the targeted phases can be synthesised in the laser peak region, i.e. Ni_3Al in 3Ni-Al film, Cu_3Sn in Cu-4Sn system and polycrystalline Si in amorphous Si film. And the original phase could be maintained in the laser power valley regions.

Keywords: nano/micro structuring, surface composite effect, recrystallization, local phase formation

1 INTRODUCTION

It is observed from nature that certain insects possess the optimised surface fixing configurations against sliding and the tree body consists of different kinds of micro/nano-tissues with optimised properties to prevent breaking by wind [1 to 3]. The effect that the performance of the material are strongly enhanced by combination of materials with different properties in a well distributed manner can be called the composite effect. One prominent characteristics of these natural structures is their micro/nano-scaled periodicity [1]. If such topological and micro-structural structures can be created on surface, the material would be expected to exhibit superior surface composite effect. The objective of this work is to show how the biomimetic surface composite effects in different materials can be achieved by interfering laser beams.

Laser irradiation could induce phase transformation and formation due to thermal interaction[1] with sample surface. Laser thermal energy could generate evaporation, melting and thermal conduction [4, 5]. With laser interference, the laser power input could be distributed at interference dots or lines. Due to the short duration of thermal exposure by pulse laser, the sample surface could be modified under precise control of the laser irradiation. The schematic drawing of a two-beam interference is shown in Fig. 1. Material systems are employed in this work to demonstrate that both the topographic and phase surface structuring formed by laser interfering beams could optimise the overall function of the materials.

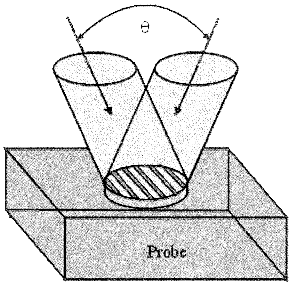

Fig. 1 Schematic drawing of the two-beam interference pattern.

2 EXPERIMENTAL PROCEDURES

High power Nd:YAG pulsed laser is used in this study. The primary laser beam is separated into two, three or more partial beams and then overlap again by mirrors on the sample surface where interference pattern forms. By changing wavelength (λ) of the laser and the including angles (θ) between the split beams, one can change the period P of the patterned structure according to $P = \frac{\lambda}{2 \cdot \sin\theta}$. The laser interference configuration and other parameters will be described separately for each system studied in the following.

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3 RESULTS AND DISCUSSION

3.1 Interference pattern

Two beam interference produces one dimensional linear pattern form, and three beam interference two dimensional dot array (Figure 2(a) and (b)). The total intensity of the interference field is four times larger relative to that of the individual beam for the two beam interference, and nine times larger for the three beam, and 36 time larger for the six beam interference. This means that the energy can be localised in definite points or areas from multi-beam interference.

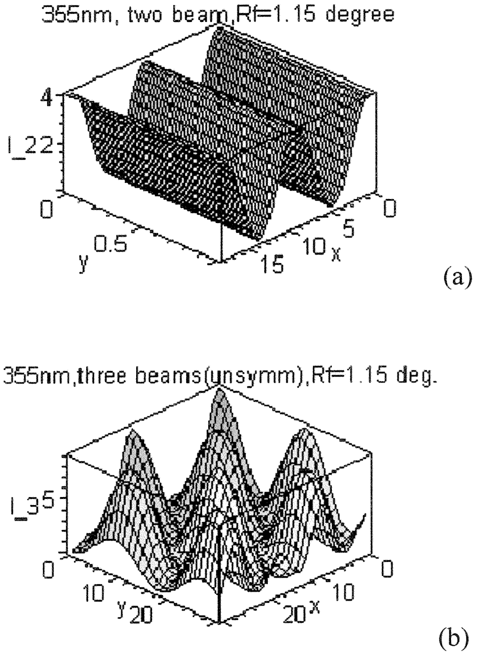

Fig. 2 Intensity distribution of two (a) and three beam interference patterns (b). the period of two beam is 9µm, while that of three beam are different in x (c) and in y (d) direction.

3.2 Ni_3Al intermetallic film

Polycrystalline Ni_3Al is very brittle at room temperature because of grain-boundary fracture [6]. Therefore it would be used to disperse into a softer, more ductile Ni-matrix. The main idea from laser interference process is that Ni_3Al can be spatially formed on a homogenous matrix according to the laser interference pattern. Thus the structured surface combines the ductility of the matrix Ni and the strength of Ni_3Al. The 3Ni-Al film is sputtered on Si with a thickness of 900 nm by magnetron sputtering technique. The Ni-Al atom ratio of the layer sputtered is maintained at 3:1.

The temperature of the laser treated area can reach as high as 1200 K. Crystallisation is possible to happen with such a high temperature. X-Ray analysis shows that an intermetallic reaction has occurred between Ni and Al after laser structuring. The two-dimensional structures on 3Ni-Al thin film surface is shown in Fig. 3.

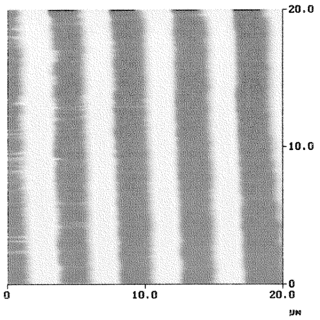

Fig. 3 The structured surface on 3Ni-Al thin film.

Indentation measurement is carried out across the laser treated area by a nano-indentation in AFM. The hardness in laser peak area-where laser intensity is maximum and is profoundly higher than that of the laser valley area where laser intensity is minimum. The average hardness in laser treated area is close to 12 GPa, while that in the laser untreated area is bigger than 4 GPa Fig. 4.

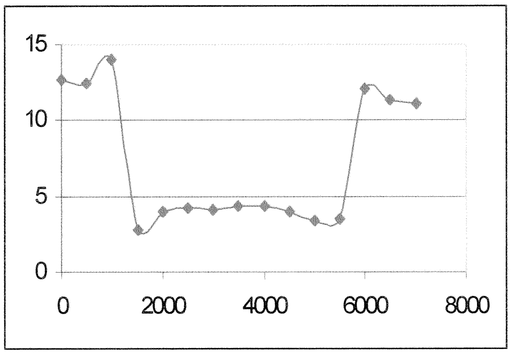

Fig. 4 The modulation of hardness though laser interference structuring Ni_3Al.

Therefore the hardness is periodically modified by laser interference. And alternatively two opposite properties, hard Ni_3Al phase is successfully produced on the surface exposed in laser intensity maximum, and soft and ductile Ni phase in laser intensity minimum.

3.3 Sn layer on Cu matrix

Sn/Cu is one of the most important contact material used in automobile industry. In the hot dipped tined CuSn4 sample, x-ray diffraction indicates that there are a layer of pure tin, a Cu_6Sn_5 and a very thin Cu_3Sn film on Cu matrix. After the laser structuring, the Cu_3Sn film is observed to have grown and the Cu_6Sn_5 layer thickness have decreased. It can be seen with AFM and nano-indentation measurements that this phase transformation is local and periodical. The soft tin phase is detected on topological peaks and the hard intermetallic phase is grown on valley [7].

The hardness of the structured samples was studied under the nano-indentation AFM. Fig. 5 shows the image of the nano-indentation AFM. The measurements are carried out in the laser peak area and in laser valley area. The results are summarised in Table 1.

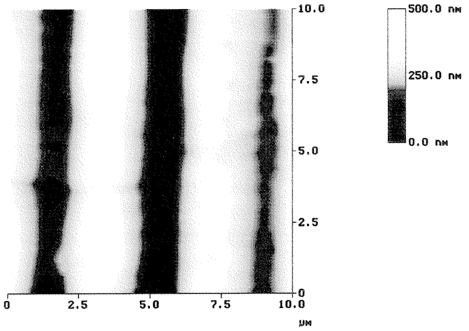

Fig. 5 Atomic force graph of a laser structured hot dipped tinned CuSn4.

Hardness (GPa)	Valley	Peak
No.1	0.62	0.43
No.2	0.51	0.45
Average (GPa)	0.57	0.44

Table 1 Nano-hardness in Peaks and Valleys on structured CuSn4 surface.

It can be seen from Table 1 that the laser peak area has higher hardness than the laser interference valley area. This modulation of hardness is over the whole laser irradiated area.

2.4 Amorphous Si film

The amorphous Si film is coated on glass by the process of hot-wire-deposition (HW-CVD). The thickness are in the range of 100 to 400 nm. The interference structures are analysed by WLI. The period of 4.3 μm is produced for one dimensional linear structure. Surface morphology in amorphous Si film after laser structuring is investigated by AFM. As shown in Fig. 6, sub-micrometer Si crystals in amorphous Si layer are generated along the periodic lines. The crystallised zone takes nearly 70% of the whole period. There are the “cold line” between the crystallised zones where the laser intensity is tend to the minimum.

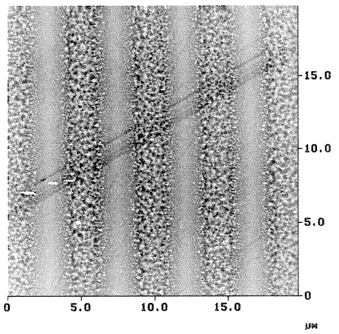

Fig. 6 Linear structured surface morphology of amorphous Si film.

From the edge of the structure line, the sizes of the crystallite increase gradually from couple tens nm at the edge the crystallised zone to some hundred nm in the middle of the zone. This is because the temperature in the middle of each line is high enough to initiate the crystallisation; while the temperature is a little lower for the transformation around the edge of the laser intensity. Therefore a structure with alternative crystallised and uncrystallised zones is successfully produced.

4 CONCULSIONS

From this work, it can be concluded that under suitable laser interference conditions, the targeted phase can be synthesised periodically distributed according to the laser interference pattern. In the laser peak region, i.g. Ni_3Al in 3Ni-Al film, Cu_3Sn in Cu-4Sn system and polycrystalline Si in amorphous Si film. And the original phase could be maintained in the laser power valley regions. The hardness distribution across the structured surface shows that the surface composite effect can be realised by laser interference process. The topography and phase combinations made by laser interference pattern provide powerful tool to achieve these bio-inspired surface composites.

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