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ORIENTED PROLATE SILVER PARTICLES IN GLASS - CHARACTERISTICS OF NOVEL DICHROIC POLARIZERS

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Abstract -- *Nanosized spherical silver particles in glass, introduced by an ion exchange plus annealing procedure, have been deformed at elevated temperatures to uniformly arranged prolate spheroidal particles by homogeneous glass stretching at constant stress. Thereupon, the optical absorption band splits into two bands according to the long and short axes of the deformed particles. Since colour and polarizing effect of these particles may widely be controlled by variation of their aspect ratio this technique enables the fabrication of novel dichroic polarizers with spectral characteristics throughout the whole visible range. Local thermally induced shape relaxation of deformed particles makes colour structuring possible on the micrometer scale. Characterisation of these materials by optical absorption spectroscopy and transmission electron microscopy demonstrates the influence of deformation and shape relaxation on their spectral and polarizing properties. ©1999 Acta Metallurgica Inc.*

INTRODUCTION

Spherical Ag particles of various sizes and number density in soda-lime glass are readily obtained by Na/Ag ion exchange and subsequent reduction treatment [1-3]. Stretching at elevated temperatures of such coloured glasses results in elongated particles uniformly oriented along the direction of deformation. Consequently, the optical absorption of the spherical particles splits into two bands according to the long and short axes of the now spheroid-shaped particles. The position of these absorption bands may be tuned by varying the initial size of the spherical particles and the degree of glass deformation that determines the aspect ratio of the prolate particles [4,5]. Basing on this procedure, novel dichroic polarizers of high mechanical, chemical and thermal durability can be fabricated which have a wide range of dichroic colours accessible. Thermally induced shape relaxation of deformed Ag particles to a well-defined extent within sharply bounded areas [6,7] can be utilized for microstructuring with strip or pixel dimensions less than 10 μm.

EXPERIMENTAL

Spherical Ag particles of 4 - 40 nm size were formed in commercial soda-lime glass by ion exchange in a $NaNO_3/AgNO_3$ melt mixture and subsequent annealing at 560 °C. Stretching of the coloured glasses was done at 650 °C by pulling at constant stress of 50 - 150 N/ mm^2 so to obtain elongated particles (mean aspect ratio 2.4 - 5.5). Microstructuring is achieved by patterned laser light illumination or electron beam lithography which allows continuous proc-

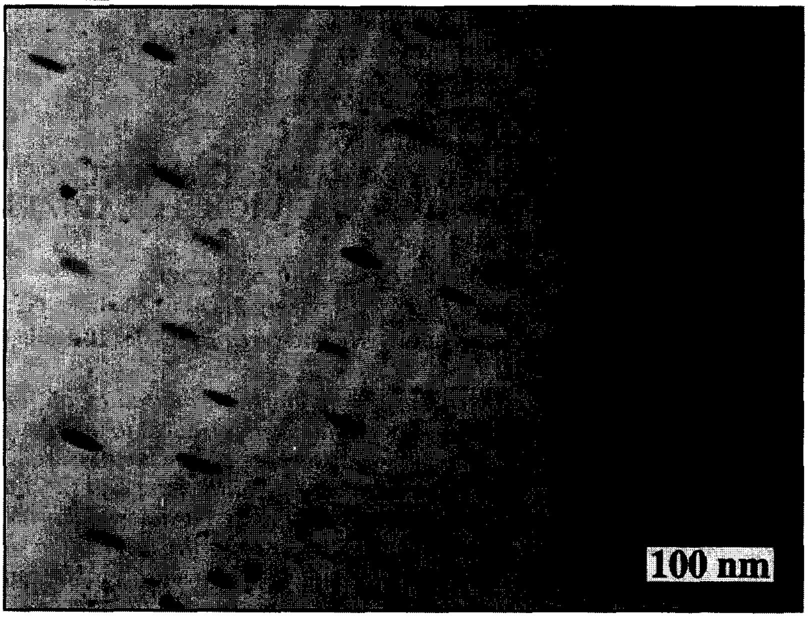

Fig. 1: Prolate Ag particles (mean aspect ratio 2.46) deformed by glass stretching at 50 N/mm^2

essing of glass sheets up to 30 cm width by means of a cascaded air lock system.

RESULTS AND DISCUSSION

The Fig. 1 demonstrates uniform arrangement of deformed particles for a glass stretching factor of about 4 leading to a mean aspect of 2.46. Because of the surface curvature restrictions only particles larger than a critical value D* are affected by the deformation process. The correspond-

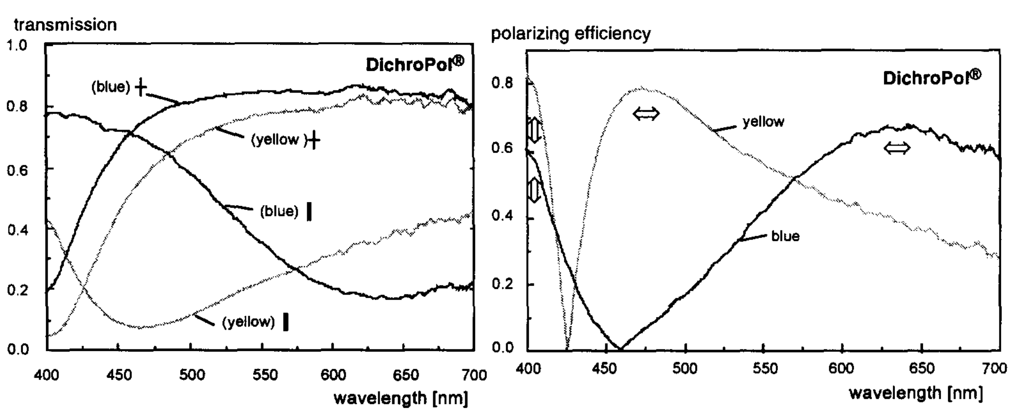

Fig. 2: Transmission of parallel (‖) and perpendicular (+) linearly polarized light, (left plot), and polarization, parallel (⇕) and perpendicular (⇔) to stretching direction, (right), of two types of dichroic glass polarizers (blue, and yellow)

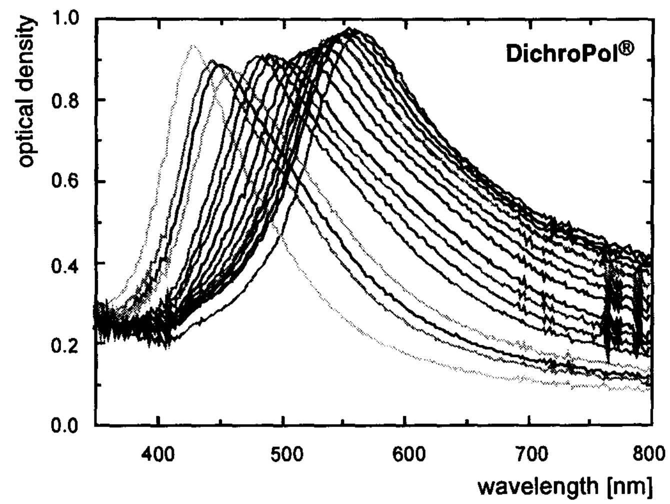

Fig. 3: Optical density spectra of a stripe patterned 17 steps colour wedge fabricated by local thermally induced shape relaxation with linear increase of irradiation dose

ing spectra for this dichroic glass polarizers (yellow type), representing its colour (transmission) and polarizing effect, are shown in Fig. 2 together with those for another, heavier stretched glass (blue type). The glass stretching factor of the latter one is about 6 leading to a mean aspect ratio of the deformed particles of 3.38.

Fig. 3 shows a set of spectra from a striped colour wedge demonstrating the possibilities of microstructuring by means of local thermally induced shape relaxation. The stripes (160 μm

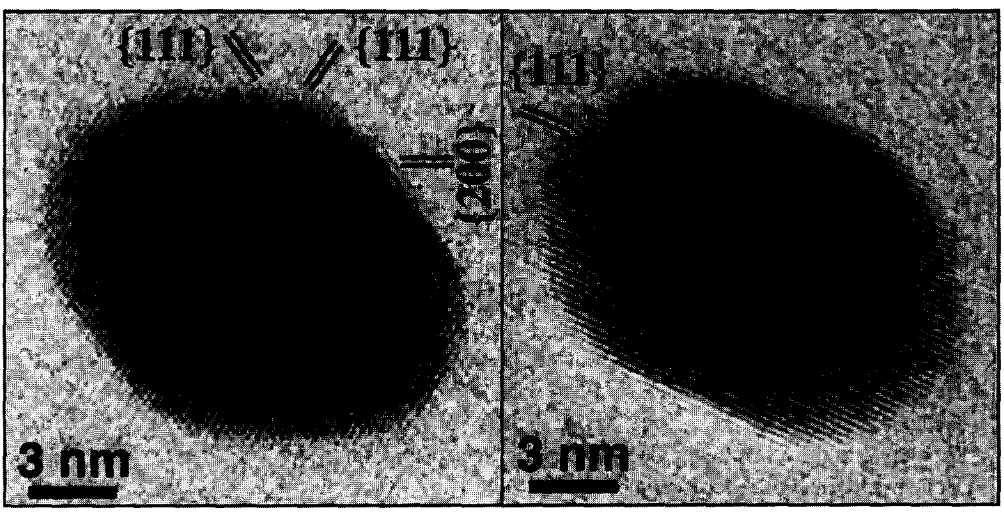

Fig. 4: Spindle and rod-like shape deviations from the spheroid-shape depending on the orientation of the particle crystal lattice with respect to the stretching direction

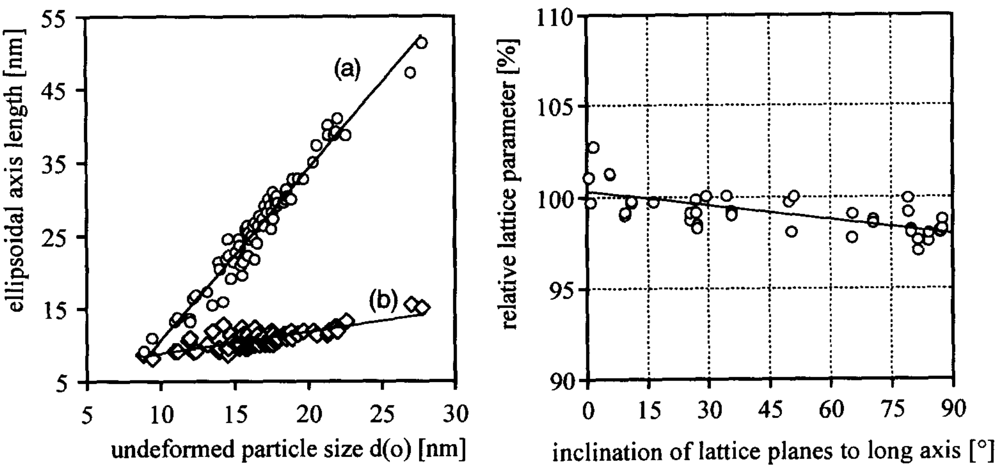

Fig. 5: Spheroid axes length as a function of the undeformed particle size d(o), (left plot); and {111}lattice fringe spacing in dependence on their inclination to the long axis, (right)

width; 40 μm spacing; 70 mm length), each one represented by its spectrum, were fabricated with stepwise linear increase of the irradiation dose during patterning.

The uniformity of particle deformation in such materials is still limited for two reasons: *(i)* a random orientation of their crystal lattice with respect to the stretching direction, and *(ii)* the distribution of undeformed particle sizes. The first one produces, deviating from the spheroid, rod-like and spindle shapes, in particular, for stretching parallel and perpendicular to {111} lattice planes, respectively, as shown in Fig. 4. The second one leads to a distribution of spheroid axes lengths as may be recognized from Fig 5(a). Both contribute to a certain distribution of the aspect ratio the width of which is decisive for the applicability for filtering and polarizing purposes. Lattice inhomogeneities with respect to the stretching direction have been detected by high resolution electron microscopy. Evaluation of the spacings of lattice plane fringes as a function of their inclination to the long axis as shown in Fig. 5(b) reveals a lattice contraction opposed to the stretching direction. Such compressive strains frozen-in within the glass matrix need to be removed carefully since they could influence the reliability of spectral characteristics of dichroic glass polarizers.

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