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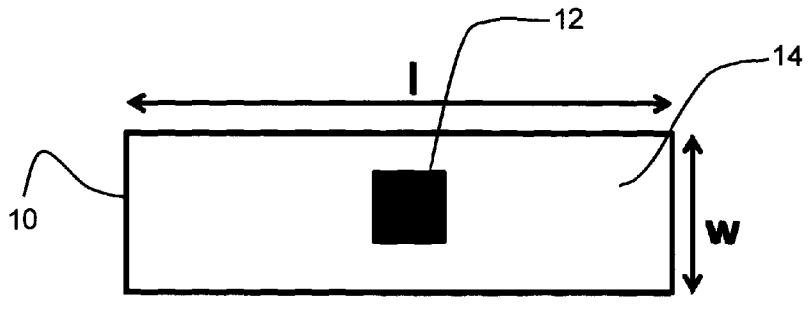



Fig. 1

(57) Abstract: An elastically deformable sheet is disclosed, for use in flexible and stretchable electronics applications. The sheet is formed from a cross-linkable polymer. The sheet has a first region having a first elastic modulus value and a second region having a second elastic modulus value, the first and second elastic modulus values being different. The ratio between the first and second elastic modulus values is at least 1.1. The first and second regions of the sheet have substantially the same composition. The difference in the first and second elastic modulus values being is by a difference in the degree of cross-linking of the cross-linkable polymer at the first and second regions. In a specific use in stretchable electronics, an array of islands of the relatively stiff material is to be formed in the sheet, separated by relatively soft material. Individual electronic components are mounted at the stiff islands and elastically deformable electrical interconnects are formed between the individual electronic components.

WO 2011/124898 A1

# ELASTICALLY DEFORMABLE SHEET WITH REGIONS OF DIFFERENT ELASTIC MODULUS FOR STRETCHABLE ELECTRONICS

## BACKGROUND TO THE INVENTION

### Field of the invention

The present invention relates to the tuning of the properties (particularly mechanical properties, such as the elastic modulus) of polymeric materials. It has particular, but not necessarily exclusive, application to the tuning of the mechanical properties of elastomeric materials.

### Related art

In the context of the present disclosure, the term "elastically deformable" is intended to encompass flexibility (e.g. the ability of a material to accommodate mechanical deformation applied by bending, typically in one direction only or twisting) and also stretchability (e.g. the ability of a material to accommodate mechanical deformation applied by bending or pulling in one or more directions simultaneously). Furthermore the "elastically deformable" material recovers its initial configuration after cyclic mechanical loading. Typically, suitable materials allow large deformation (at least 5% strain, and sometimes significantly more than this) to be accommodated on application of a suitable stress, and yet allow a return of the material substantially to its initial configuration on removal of the applied stress.

It is known that, for some applications, it would be beneficial to be able to provide elastically deformable electronic devices, i.e. electronic devices that withstand significant elastic deformation of the overall device in storage, deployment and/or use. As mentioned above, such elastic deformation may be by way of flexing or stretching.

However, the well-developed methods of making conventional silicon-based electronic devices are incompatible with most elastically deformable materials. This is typically due to

the high temperature processing steps required for the manufacture of such silicon-based electronic devices. Additionally, conventional silicon-based electronic devices are typically unsuitable for flexing or stretching, since they are formed of brittle materials. We note here that in some configurations, even brittle materials can be considered to be flexible. For example, thinned silicon (thickness of about 100nm) is relatively flexible. However, it is not considered suitable for stretching.

Rogers et al 2010 [J Rogers, T Someya and Y Huang "Materials and Mechanics for Stretchable Electronics" Science vol. 327 (26 March 2010) 1603-1607] set out a useful review of the technical field of stretchable electronics. In particular, they review hybrid devices including populations of brittle, non-stretchable electronic components formed on a stretchable substrate with relatively strain-insensitive electrical interconnects.

Lacour et al 2005 [S P Lacour, J Jones, S Wagner, T Li and Z Suo "Stretchable Interconnects for elastic Electronic Surfaces" Proceedings of the IEEE. Vol. 93, No. 8, August 2005, 1459-1467] discuss the possibility of distributing rigid subcircuit islands over the surface of an elastically deformable polymeric substrate and forming active electrical components at the islands. The islands can be interconnected with stretchable metallization. Such interconnects were shown to remain functional when the substrate was stretched elastically to 12% strain and relaxed.

Lacour et al 2008 [S P Lacour, S Wagner, R J Narayan, T Li and Z Suo, "Stiff subcircuit islands of diamond-like carbon for stretchable electronics" J. Appl. Phys., 100, 014913 (2006)] disclose the formation of stiff subcircuit islands on an elastically deformable polydimethylsiloxane (PDMS) substrate, the substrate having thickness of 1 mm. The islands were formed by depositing a film of diamond-like carbon through a shadow mask defining the island regions. Stretchable metallized interconnects were formed between the islands in a similar manner as in Lacour et al 2005. During elastic stretching cycles up to 20%, it was observed that the area dimensions of the islands changed much less than the spacing between the islands.

WO 2009/111641 discloses methods for making stretchable and foldable electronic devices. A receiving substrate formed of a first material having a first elastic modulus value is coated with an isolation layer formed of a second material having a second elastic modulus value. Electronic components are then transferred onto the isolation layer. The function of the isolation layer is to isolate the electronic device from strain applied to the receiving substrate. The electrical components can be connected via strain-insensitive interconnects. In some embodiments, the device is structured so as to provide a neutral mechanical surface at which the electrical components are mounted. The neutral mechanical surface is provided by patterning of one or more layers of the device, to provide a difference in thickness of the device across the area of the device.

WO 2005/104756 discloses methods for forming structural features on a flexible substrate using soft lithographic techniques. In one embodiment, the flexible substrate is formed of a polymer layer having varying thickness, the thickness varying in accordance with a desired pattern. The elastic modulus of the polymer layer varies through the thickness of the polymer layer, from a low value at the surface to a higher value at the centre of the thickness of the polymer layer.

WO 2008/055054 discloses the manufacture of flexible and bendable plastic substrates for placement of electronic components. The substrates are formed using ink lithography to form a pattern of varying thickness across the area of the substrate.

## SUMMARY OF THE INVENTION

The present inventors have realised that it would be of great interest to develop a substrate material that can be formed in a relatively straightforward manner, the substrate material being elastically deformable (e.g. flexible and/or stretchable), but having mechanical properties that are tuned to different desired values in different regions disposed across the area of the substrate. It would be particularly beneficial, in the view of the inventors, to be able to develop a substrate material that allows such tuning of the mechanical properties

without the need to vary the composition of the different regions of the substrate, since such compositional variation can be difficult to achieve.

In order to address this interest, the present inventors have devised the present invention.

In a general aspect of the present invention, the inventors provide an elastically deformable polymeric sheet with different regions located across the area of the substrate having different elastic modulus values, the different regions of the sheet having the same composition.

In accordance with a first preferred aspect of the invention, there is provided an elastically deformable sheet formed from a cross-linkable polymer, the sheet having a first region having a first elastic modulus value and a second region having a second elastic modulus value, the first and second elastic modulus values being different, the ratio between the first and second elastic modulus values being at least 1.1, wherein the first and second regions of the sheet have substantially the same composition, the difference in the first and second elastic modulus values being provided by a difference in the degree of cross-linking of the cross-linkable polymer at the first and second regions.

In a second preferred aspect, the present invention provides a method of manufacturing an elastically deformable sheet according to the first aspect, the method including providing an uncured sheet of:
a matrix material either formed of a monomer or pre-polymer capable of forming a polymer, or formed of a polymer, the polymer being capable of being cross-linked;
a cross-linking component; and
an activatable cross-linking controlling component, wherein the activatable cross-linking controlling component is capable of affecting the ability of the cross-linking component to cross-link the matrix material,
the method further including the steps:
selectively activating the activatable cross-linking controlling component in at least a second region of the uncured sheet; and

curing the sheet to effect cross-linking, thereby to form the elastically deformable sheet having said first and second regions with different elastic modulus values.

In a third preferred aspect, the present invention provides a method of manufacturing an elastically deformable sheet according to the first aspect, the method including providing an uncured sheet of:
a matrix material either formed of a monomer or pre-polymer capable of forming a polymer, or formed of a polymer, the polymer being capable of being cross-linked; and
an activatable cross-linking component, wherein the activatable cross-linking component is capable of being activated to cross-link the matrix material,
the method further including the steps:
selectively activating the activatable cross-linking component in at least a first region of the uncured sheet; and
curing the sheet to effect cross-linking, thereby to form the elastically deformable sheet having said first and second regions with different elastic modulus values.

In a fourth preferred aspect, the present invention provides a use of an elastically deformable sheet according to the first aspect as a substrate for one or more electronic components.

In a fifth preferred aspect, the present invention provides an electronic device including a plurality of individual electronic components, the individual electronic components being mounted on an elastically deformable sheet according to the first aspect, particularly at respective first regions of the elastically deformable sheet, elastically deformable electrical interconnects being formed between the individual electronic components.

Preferred and/or optional features of the invention will now be set out. These are applicable to any aspect of the invention either singly or in any combination. It is also envisaged that any aspect of the invention may be combined with any other aspect of the invention.

In some respects, the terms "elastic modulus" and "Young's modulus" are considered in this technical field to be interchangeable. To that extent, the two terms may be considered to be

the same in this disclosure. However, strictly speaking, "Young's modulus" refers to a linear material, whereas "elastic modulus" may refer to a non-linear material. Elastomers are typically viscoelastic and non-linear, and therefore the term "elastic modulus" is used in this disclosure.

Preferably, the ratio between the first and second elastic modulus values is at least 1.2, more preferably at least 1.3, more preferably at least 1.4 and more preferably at least 1.5. In some embodiments, the ratio between the first and second elastic modulus values can be higher, e.g. at least 2.

Preferably, the ratio between the first and second elastic modulus values is at most 1000. More preferably, this ratio is at most 500, more preferably at most 100, more preferably at most 50, more preferably at most 10.

Preferably, the elastically deformable sheet further includes a third region having a third elastic modulus value, different to the first and second elastic modulus values, wherein the ratio between the first and third elastic modulus values and the ratio between the second and third elastic modulus values are independently at least 1.05 or at most 0.95.

Preferably, the ratio between the first and third elastic modulus values and the ratio between the second and third elastic modulus values are independently at least 1.1 (more preferably at least 1.2) or at most 0.9 (more preferably at most 0.8).

Preferably, the third region has substantially the same composition as the first and second regions of the sheet, the differences in the first, second and third elastic modulus values being provided by a difference in the degree of cross-linking of the cross-linkable polymer at the first, second and third regions.

In some embodiments, the elastically deformable sheet may have fourth and optionally fifth, sixth, seventh, etc. regions, each region having respectively different elastic modulus values.

Preferably, the elastically deformable sheet has at least one zone across which the elastic modulus value for the material of the sheet varies gradually, the zone incorporating at least part of the first and second regions, the composition of the zone being substantially uniform.

The first region may have any suitable shape. For example, the first region may be formed as a strip or track. The first region may be formed in a pattern on the sheet. The first region may be formed adjacent the second region. Alternatively, the first region may be adjacent a third region (interposed between the first and second region) or a zone across which the elastic modulus value for the material of the sheet varies gradually.

Preferably, the elastically deformable sheet includes an array of said first regions. The first regions may have different shapes. However, more preferably, the first regions have substantially similar shapes.

The first regions may be formed as islands, each island surrounded by the second region or a corresponding array of second regions. Alternatively, each first region may be surrounded by (or adjacent to) a zone across which the elastic modulus value for the material of the sheet varies gradually.

Preferably, the differences in elastic modulus values in the different regions of the sheet remain throughout the useful lifetime of the sheet. In particular, the differences in elastic modulus values should not change during normal storage of the sheet. In this sense, these differences in elastic modulus values are preferably irreversible.

Preferably, each individual electronic component is mounted on the elastically deformable sheet via a mounting layer. Preferably, the mounting layer is formed in register with the first region. Where there is an array of first regions, respective corresponding mounting layer islands may be located in register with the first regions. The mounting layer may be formed of a material having a elastic modulus value that is at least 10 times the elastic modulus value of the first region. More preferably, the mounting layer may be formed of a material having a elastic modulus value that is at least 100 times (or preferably at least 1000 times) the elastic

modulus value of the first region. For example, the mounting layer may be formed of silicon, diamond-like carbon (DLC) or silicon nitride. These materials have elastic modulus values of about 100 GPa. Alternatively, the mounting layer may be formed of a polymeric material such as polyimide or parylene. These materials have elastic modulus values of about 5 GPa.

Preferably, the first and second regions of the sheet have substantially the same thickness, or substantially the same thickness variation. Where a third and/or subsequent regions are present, preferably these regions of the sheet have substantially the same thickness, or substantially the same thickness variation.

Preferably the elastically deformable sheet has a substantially uniform thickness. However, it is noted that it is possible to form the sheet into a shape having thickness variation. For example, it is possible to form the sheet so that it has holes formed through it. Such thickness variation may be applied before or after curing.

Typically, the maximum suitable thickness of the sheet is determined (at least in part) by the maximum thickness at which the activatable cross-linking controlling component (or the activatable cross-linking component) can be activated in order to control the degree of cross-linking of the composition. A maximum suitable thickness may be up to 1 mm, and possibly greater (e.g. up to 2 mm, up to 3 mm, up to 4 mm, and up to 5 mm is considered to be possible). There is no particular lower limit, but it is expected that at thickness less than about 1-10 μm, the sheet will have insufficient mechanical strength to have utility. At such low thickness, the sheet may be mounted on a substrate, in order to provide some mechanical support.

Alternative configurations other than sheet-form may be possible. For example, the product may be formed as a block, rod or other shape. The product may be moulded or machined to a desired complex shape.

Preferably, in the method of manufacturing the sheet, the selective activation of the activatable cross-linking controlling component (or of the activatable cross-linking

component) is carried out by selectively controlling an irradiation flux and the first and/or second regions. This selective control of the irradiation flux may be carried out using an irradiation source and a mask adapted to the form of the first and second regions. In a manner that will be understood by the skilled person, the mask can allow different amplitudes of radiation flux through different parts of the mask. Where third and/or subsequent regions are to be provided in the sheet, the mask may be adapted to the form of said third and/or subsequent regions.

Preferably, the irradiation flux is electromagnetic radiation (e.g. ultra violet radiation, visible light or infra red radiation) or a particle beam (e.g. electron beam, ion beam or alpha particle beam). Ultra violet radiation is most preferred. Suitable wavelengths in the range 280-390 nm are most preferred.

In the case where the irradiation flux is ultra violet radiation, a mask can be formed of glass having a suitable pattern of chromium metal film formed on the glass. In order to form a zone of graduated elastic modulus value, the distribution and density/opacity of chromium metal formed on the glass can be correspondingly controlled, in order to control the attenuation of the radiation through different parts of the mask.

Preferably, the sheet is subsequently cured. This can be at elevated temperature, but for some materials, curing is possible at room temperature. Preferably, the curing temperature is at least 40°C. More preferably, the curing temperature is at least 50°C or at least 60°C. The sheet may be cured for at least 1 hour, more preferably at least 5 hours, at least 10 hours or at least 20 hours.

Preferably, the elastically deformable sheet is formed from a single cross-linkable polymer.

Preferably, the elastically deformable sheet is formed from an elastomeric polymer. For example, the elastically deformable sheet may be formed from a thermoset rubber (e.g. a vulcanised rubber) or a thermoplastic rubber. In general, an elastomeric polymer is considered to be any rubbery material composed of long, chainlike molecules that are capable

of recovering their original shape after being stretched (e.g. to 5% strain, or even to 10% or 20% strain). Under normal conditions the long molecules making up an elastomeric material are irregularly coiled. With the application of force, however, the molecules straighten out in the direction in which they are being pulled. Upon release, the molecules spontaneously return to their normal compact, random arrangement.

The polymer may be at least one selected from the group consisting of a silicone polymer (polysiloxane). For example, suitable polysiloxanes include: polydimethylsiloxane, polydimethyl-methylphenylsiloxane, polymethyl-phenylsiloxane, polyphenyl-T resin, polyfluorosilicones and tetramethyltetra-phenyltrisiloxane. Alternatively, the polymer may be an acrylic polymer, a polyurethane or a nitrile rubber.

The activatable cross-linking controlling component can be any component which can control the cross-linking activity of the cross-linking component, e.g. in response to a region-specific external stimulus. For example, the cross-linking component may be capable of being disabled by activation of the activatable cross-linking controlling component. For example, the activatable cross-linking controlling component may be a photoactive component such as a photo-inhibitor.

For some embodiments, a suitable activatable cross-linking controlling component is benzophenone. Irradiation of benzophenone with UV light forms benzophenone radicals. Such radical can abstract hydrogen atoms from hydrogen-containing groups (e.g. silicon hydride groups) in the cross-linking component, thereby preventing the reacted hydrogen-containing groups from cross-linking with the matrix material. Other suitable activatable cross-linking controlling component may also be aromatic ketones containing a phenyl group.

The activatable cross-linking component can be any component which can be controlled (by activation) to cross-link the matrix material. For example, the activatable cross-linking component may be a photoactive component such as a photo-initiator. A suitable photoinitiator is considered to be 2,2-dimethoxy-2-phenyl acetophenone (DMAP).

Preferably, at least one (and preferably both) of the first and second elastic modulus values is in the range 0.1-100 MPa. More preferably, the upper limit here may be lower, e.g. 50 MPa or 25 MPa, allowing for greater elastically deformabilityof the sheet at a given thickness. The values of the elastic modulus in the third and/or subsequent regions may also lie in this preferred range.

Preferably, in use, the strain experienced by the elastically deformable sheet is at least 1% tensile strain (more preferably at least 5% tensile strain). This may be provided uniformly in the elastically deformable sheet (e.g. by uniaxial stretching) or it may be the strain experienced by only a part of the elastically deformable sheet as part of a more complex deformation mechanism such as bending or folding. Preferably, this strain is elastic strain in the sense that the elastically deformable sheet recovers to its previous configuration once released.

The elastically deformable sheet may be a composite material. For example, the polymer may be initially loaded with stiffening structures e.g. carbon nanotubes or protein fibres (see, for example, T. Oppenheim, Acta Biomaterialia 6 (2010) 1337-1341), or electrically conducting particles e.g. gold or inorganic nanowires.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a cured elastically deformable sheet according to an embodiment of the invention in an un-stretched configuration.

Fig. 2 illustrates the cured elastically deformable sheet of Fig. 1 in a stretched configuration.

Fig. 3 illustrates a method for manufacturing a elastically deformable sheet according to an embodiment of the invention.

Fig 4 shows the stress-strain curves for strips 22a, 24a and 26a in Fig. 3.

Fig. 5 shows elastic modulus values as determined based on 10-15% strain and as determined based on 1-2% strain, for regions subjected to different UV doses.

Fig. 6 shows the effect of UV dose on elastic modulus (E).

Fig. 7 shows the effect of curing time on the elastic modulus (E) of a region of a sample having a uniform UV dose.

Fig. 8 shows a comparison of the behaviour of elastic modulus (E) with ageing.

Fig. 9 shows the effect of curing time on elastic modulus (E) for PP-PDMS in comparison with conventional PDMS.

Fig. 10 shows the results of testing for the elastic modulus (E, over 10-15% strain and over 1-2% strain) for the samples shown in Fig. 3.

Fig. 11 shows a schematic cross section view of a rigid platform (island) formed on an elastically deformable elastomeric substrate.

Fig. 12 illustrates a use of an elastically deformable elastomeric substrate according to an embodiment of the invention.

Figs. 13-15 show cross sectional strain maps derived from COMSOL models of the principal strain at the interface from a 1 μm thick island attached to the surface of a 100 μm thick PDMS substrate. In each case a strain of 0.2 (20%) is applied to the PDMS substrate.

Fig. 16 shows results of simulation as in Figs. 13-15.

Fig. 17 assists in illustrating the teaching of Figs. 13-16.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS, FURTHER OPTIONAL FEATURES

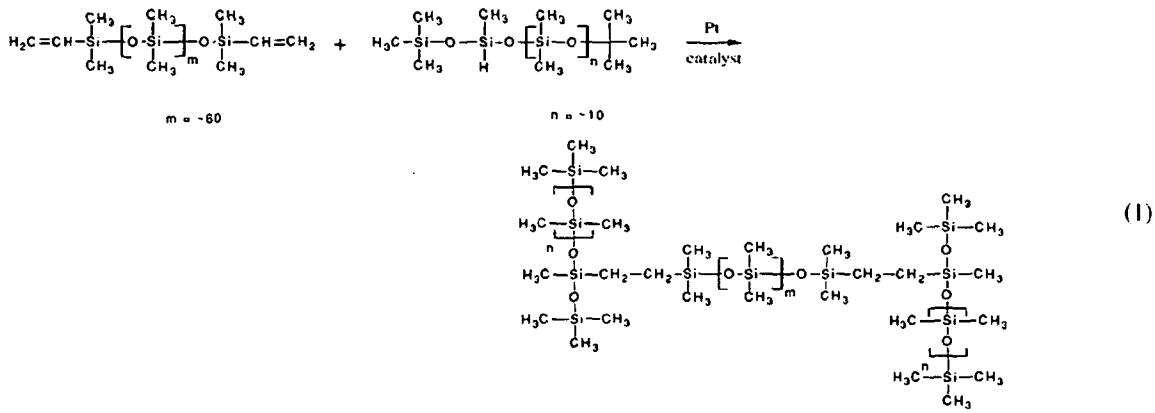
The content of all of the published documents identified herein is incorporated herein by reference in its entirety.

Bhagat et al 2007 [A A S Bhagat, P Jothimuthu, I Papautsky "Photodefinable polydimethylsiloxane (PDMS) for rapid lab-on-a-chip prototyping" Lab. Chip, 2007, 7, 1192-1197] disclose a method of patterning polydimethylsiloxane (PDMS) directly, in order to provide PDMS sheets containing patterns of holes through them, suitable for use in lab-on-a-chip applications. Benzophenone is added to PDMS, which is then patterned with UV light exposure, cured and developed. Benzophenone is a photosensitizer used to initiate free-radical polymerization by UV light of acrylates and monomers with other functional groups. The PDMS is exposed to UV light with wavelength less than 365 nm for about 10 minutes at 12 $mWcm^{-2}$. Following this exposure, a post-exposure bake was carried out at 120°C for 40-120 seconds. In this pos-exposure bake, the unexposed regions are cured and the exposed regions remain uncured. The uncured PDMS is removed using toluene and rinsed in isopropanol. Bhagat et al 2007 explain that the process offers the advantages of PDMS elastomer, yet simplifies fabrication of the profiled surface of the elastomer by eliminating the need for a master in a moulding technique.

Jothimuthu et al 2009 [P Jothimuthu, A Carroll, A A S Bhagat, G Lin, J E Mark, I Papautsky "Photodefinable PDMS thin films for microfabrication applications" J. Micromech. Microeng. 19 (2009) 045024] provides a similar disclosure to Bhagat et al 2007, except that a fuller explanation of the expected mechanism for inhibition of cross-linking is set out. In so far as this explanation is of importance in understanding embodiments of the present invention, this explanation is reproduced from Jothimuthu et al 2009 below, with reference to equations (1)-(4).

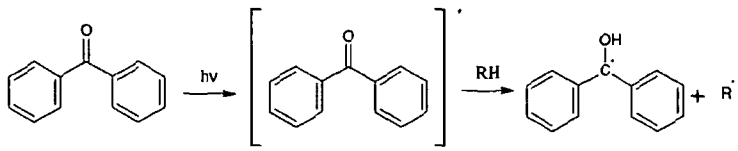
In traditional PDMS fabrication, structures are formed as negative replicas by curing a two-component silicone elastomer mixture (base monomer (pre-polymer) and curing agent) over a

master template. In terms of chemical structure, the base pre-polymer is composed of about 60 repeating units of $-OSi(CH_3)_2-$ terminating with a vinyl–$CH=CH_2$ group (Sylgard 184, Dow Corning). The curing agent is similar, but is much smaller with only about ten repeating units and has periodic silicon hydride $-OSiHCH_3-$ units. During the curing step, the hydrosilation of olefins takes place, i.e. the base and the curing agent crosslink forming $-Si-CH_2-CH_2-Si-$ complexes. This is illustrated in equation (1) below. The resulting structure is insoluble and is completely cured:




(1)

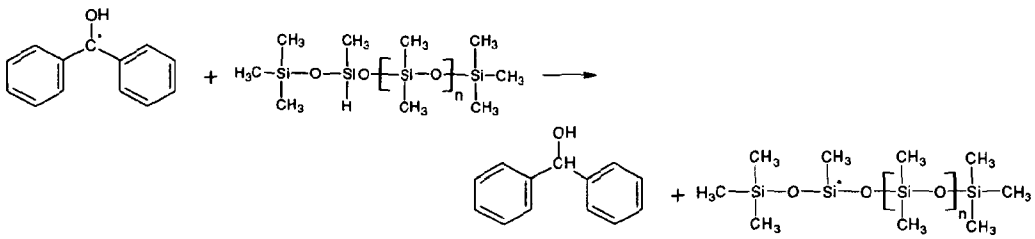
The crosslinking mechanism of the photoPDMS mixture, however, is different. Although there are several possible reaction mechanisms that could account for the benzophenone's inhibition of crosslinking, the most likely mechanism is based on the reduction of carbonyl groups by hydrosilanes. When benzophenone (also known as diphenyl ketone) is mixed with PDMS and irradiated using UV <365 nm, a benzophenone radical is formed (equation (2)):



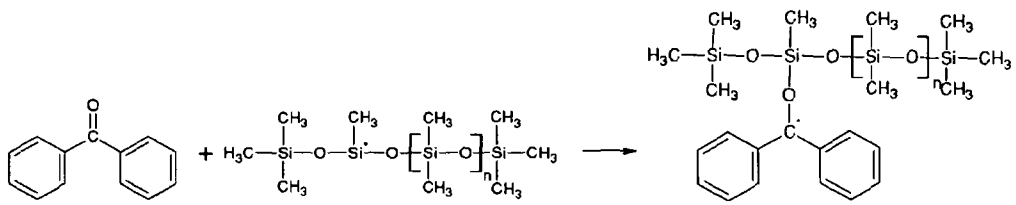

(2)

The benzophenone radicals react with the silicon hydride groups present in the PDMS crosslinker (equation (3)). This hydrogen abstraction of benzophenone prevents the

crosslinker from undergoing traditional organometallic crosslinking with the PDMS oligomer and creates a crosslinker radical. The radical can then undergo either disproportionation to form a stable soluble complex with a Si=C bond or radical coupling to form with a Si–Si bond:



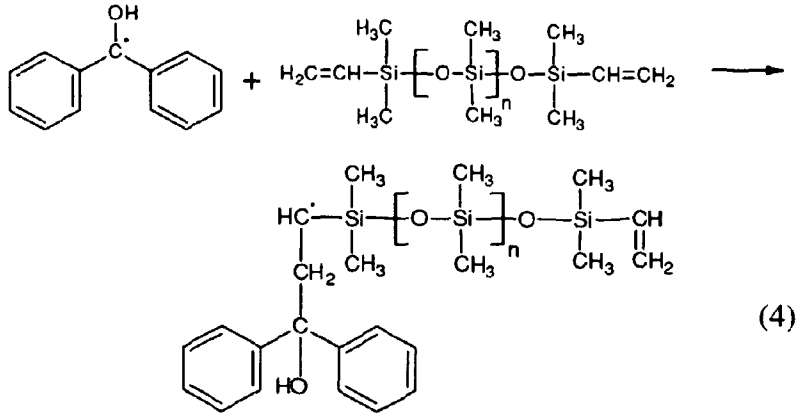
(3a)



(3b)

Alternatively, benzophenone radicals react with the base monomer forming short complexes (equation (4)), preventing them from crosslinking with the curing agent. This can be observed from the post-exposure bake where the unexposed PDMS is cured and crosslinked, while the exposed PDMS is washed away in toluene:

16



(4)

Both the microelectronics and microsystems sectors employ elastomers in their process flow. Elastomers, rubber-band like materials, can be used as substrate, encapsulation material, and structural materials. Independently of its manufacturing process, a given commercial elastomer typically has a known elastic modulus (which may vary with various factors, such as the temperature of use), which ranges between 0.1MPa to 100MPa.

The preferred embodiments of the present invention provide a method to produce an elastomeric sheet or film, with a photo-tuneable elastic modulus (E), which can be patterned by UV exposure. The resulting film may be a single continuous film of a chosen and uniform modulus or a single continuous film with localised regions of selectively targeted elastic moduli. Once UV exposed and cured, i.e. once the elastomer is fully crosslinked, no further processing or additional material is required. The obtained elastomeric structure has embedded patterns of "programmed" compliance in a continuous film of uniform thickness.

Whilst the method has been used with elastomers, we believe it can be expanded to further cross-linkable polymers (of 2 or more components).

Elastomers are synthesized by chemically linking together molecules to form a network. Part A refers to the base monomer (or pre-polymer), and part B refers to the cross-linker molecule. The cross-linker density of the elastomer, PartB/PartA, affects its mechanical properties: the higher the density of cross linkage, the higher the resulting elastic modulus (typically up to a predetermined limit).

The mechanical properties (such as the elastic modulus) of an elastomer can therefore be altered by limiting and/or controlling the amount of cross linking which occurs in the material. This can be achieved by minimizing the concentration of cross-linking component (part B) used to cross link the base monomers (Part A) or by limiting the curing time.

For example, Schneider et al 2008 [F Schneider, T Fellner, J Wilde, U Wallrabe "Mechanical properties of silicones for MEMS" J. Micromech. Microeng. 18 (2008) 065008] disclose some mechanical properties of silicones for microelectromechanical systems. Two products were assessed: RTV 615 from Bayer Silicones and Sylgard™ 184 from Dow Corning. Such materials are disclosed as having Shore-A hardness of 50 and 44 respectively. Schneider et al 2008 carry out materials characterization of these materials in accordance with DIN 53504 (German Industry Standard, now withdrawn), specifically to measure elastic modulus. These materials were each manufactured with a "monomer" and a hardener combined at a weight ratio of 10:1. Lower viscosity for the mixture can be achieved by adding a thinner. At 0% thinner, elastic modulus of these materials was found to be about 1.2 MPa and about 1.8 MPa for these materials respectively.

As a further example, Eddington et al 2003 [D T Eddington, W C Crone, D J Beebe "Development of process protocols to fine tune polydimethylsiloxane material properties" 7th International Conference on Miniaturized Chemical and Biochemical Analysis Systems, October 5-9, 2003, Squaw Valley, California, USA] disclose the materials properties of PDMS based on curing parameters, weight ratio of pre-polymer to hardener, and ageing. The material used was Sylgard™ 184 from Dow Corning. At 10:1 pre-polymer to hardener weight ratio, the elastic modulus was about 1.25 MPa (cured at 100°C for 60 minutes). At 11:1 pre-polymer to hardener weight ratio, the elastic modulus was about 0.95 MPa (cured at 100°C for 60 minutes). Eddington et al 2003 carry out materials characterization of these materials in accordance with ASTM D638-99 (Standard Test Method for Tensile Properties of Plastics, now replaced by ASTM D638-00). Preferably, corresponding testing procedures are used in respect of embodiments of the present invention. Specifically, the elastic modulus is measured in the substantially linear, initial part of the stress-strain curve. In the present

disclosure, reference to elastic modulus should be considered to be determined based on the region of the stress-strain curve between 1 and 2% strain, unless the context states otherwise. In some measurements disclosed herein, the elastic modulus is determined based on the region of the stress-strain curve between 10 and 15% strain, but these are clearly indicated. In general, a value for elastic modulus determined based on the region of the stress-strain curve between 10 and 15% strain will be lower than that determined for the same material based on the region of the stress-strain curve between 1 and 2% strain.

Methods such as those disclosed by Eddington et al 2003 (e.g. controlling the pre-polymer to hardener weight ratio) may be adequate when a film of a uniform E is needed, and with an E close to the recommended manufacturing value. However, in the view of the inventors, limiting the curing time or using too low concentration of cross-linking component tends to produce films with poor uniformity and poor repeatability.

Instead of the approach suggested by Eddington et al 2003, the present inventors instead provide a way to pattern features on a sheet, these features having with different mechanical properties and yet the sheet having uniform composition (and preferably the sheet having uniform thickness).

In order to manufacture an elastically deformable sheet according to an embodiment of the invention, a 2-part elastomer corresponding to the PDMS material used in Bhagat et al and Jothimuthu et al 2009 was used. A corresponding photo-inhibitor (part C - benophenone) was incorporated at 3 wt%.

An uncured sheet was cast using this material. This uncured sheet is then subject to UV irradiation in the range of wavelengths from 280-390 nm. The UV power received by the mask was about 40 $mWcm^{-2}$. A suitable mask was laid on top of the uncured sheet prior to UV irradiation. The mask provides a first region at which the UV radiation is substantially prevented from reaching the uncured sheet and a second region at which substantially all of the UV radiation is allowed to reach the uncured sheet. The uncured sheet, after irradiation,

therefore has a first region, which has received a low flux of UV, and a second region, which has received a relatively high flux of UV.

The uncured sheet is then cured at 60°C for about 72 hours.

The resulting cross-link density in the cured sheet in each region depends on the initial PartB/PartA ratio, the photo-agent (PartC) type and concentration, and on the UV energy (time x power density) absorbed by the photoactive component. The mechanical properties of the resulting elastomeric film can then be accurately controlled before the curing phase, and accurately localised on the surface of the elastomer when a patterned UV mask is used. Micron scale features with a elastic modulus higher or lower than that of their surrounding elastomer matrix may be patterned within a single elastomer film (i.e. within its plane).

Note that a similar result can also be achieved by using a photo-initiator combined with part A of the elastomer. For example, Cong et al 2008 [H. Cong et al., Adv. Funct. Mater. 18 (2008), 1912-1921] refer to a two-component system using a photoinitiator of 2,2-dimethoxy-2-phenyl acetophenone (DMAP) for photo patterning films of PDMS.

The inventors have found that, in this embodiment, controlling the amount of benzophenone radicals produced by adjusting the UV light exposure time (hence the UV energy), the cross link density of the elastomer can be controlled, and the elastomer's mechanical properties can be engineered. Thus the mechanical properties can be tuned by suitable treatment of the elastomer even after the composition of the elastomer is fixed.

These preliminary tests show that it is possible to reduce the elastic modulus of the PDMS film to about one third of the expected modulus value. All of the films were tested up to 20% tensile strain. The mechanical response of the films is stable, and reproducible.

PDMS prepared in a 10:1 w/w ratio (Dow Corning Sylgard 184) has a elastic modulus of about 2 MPa. PDMS mixed with 3 wt% benzophene has a maximum modulus of 3MPa

(when not UV exposed) after curing. After 200 seconds UV exposure and curing (as set out above), the material has a elastic modulus of about 1 MPa.

The inventors consider that it is possible to increase further the achievable range of elastic modulus in a single elastically deformable sheet by increasing the concentration of the activatable cross-linking controlling component (benzophenone in this case), by varying the PartB/PartA initial ratio, and exposing the composite for extended periods of time under the UV. Of course, for all materials, there is a limit at which the sheet will no longer be elastic but will plastically deform when subjected to adequate levels of stress.

Figs. 1 and 2 illustrate a cured elastically deformable sheet 10 in (Fig. 1) un-stretched and (Fig. 2) stretched configurations. In Fig. 1, the sheet has original length l and original width w. A first region 12 has dimensions 8mm x 8mm square in this example. Other dimensions are of course possible, and may be tailored to the required application of the sheet. The first region 12 is patterned into the sheet by lack of UV exposure as discussed above, using a corresponding mask, although the first region is not necessarily observable by the human eye when the sheet is not subject to deformation (as in Fig. 2(a)). The elastic modulus of the first region is about 3 MPa in this example. The second region 14, adjacent and surrounding the first region 12, is subjected to UV exposure as discussed above. The elastic modulus of the second region is about 1MPa. The stretched sheet in Fig. 2 shows a bulge on the sides of the film where the first region is patterned and is due to the lower strain in this region of the film. This demonstrates that it is possible to pattern features (i.e. first and second regions) within a single elastomer membrane, these regions having a tuned elastic modulus.

Using a grey tone or binary UV mask, it is possible to pattern features of various elastic modulus within the same elastomeric membrane with a single exposure.

For example, Fig. 3 illustrates a simple method for manufacturing an elastically deformable sheet (formed of the same material as the embodiment described above) having first, second and third regions, each region having different values of elastic modulus. A sheet is manufactured by spin coating on a water-soluble release layer.

The sheet 20 is patterned via UV light using a mask having an opaque section, a fully transmissive section and an intermediate section, located between the opaque section and the fully transmissive section, the intermediate section providing a transmission of UV light through it of about half the amplitude allowed through the fully transmissive section.

Alternatively, a similar pattern can be achieved by using a single binary mask, and moving the binary mask during UV exposure, so that an intermediate section of the film receives overall a reduced UV dose.

Fig. 3 shows the resultant sheet after curing. The first region 22 received no UV exposure. The second region 24 received a UV dose of 24000 mJ $cm^{-2}$. The third (intermediate) region received a UV dose of 12000 mJ $cm^{-2}$.

After UV exposure, the sheet was cured at 150°C for 24 hours. Strips 22a, 24a and 26a were then cut out from the sheet and released in water. Each strip was then tested on a DMA Q800 (dynamic mechanical analysis) apparatus from TA Instruments, which is operable in order to measure various mechanical properties of elastomers in accordance with ASTM D638-99 and ASTM D638-00. The results are shown in Fig. 10.

Note that the results shown in Figs. 4-10 are based on a calculation of elastic modulus based on an assumption that the polymer follows a linear model, i.e. the elastic modulus is calculated as the slope of the strain/strain curve at low strains. Strictly speaking, this is not correct – the polymers used here are visco-elastic, non-linear materials and their tensile response should be modelled with a model such as the neo-Hookean or the Mooney-Rivlin model and their elastic modulus is function of the applied elongation. Nonetheless, the changes in elastic modulus of the polymer (fitted from the non linear model) as a function of curing temperature, UV exposure dose, etc as well as the cited ratios follow similar trends to those calculated with a linear (Hookean) behaviour of the polymer.

Fig 4 shows the resultant stress-strain curves for strips 22a, 24a and 26a. Also shown are stress-strain curves for corresponding samples subject to UV doses of 8000 mJ $cm^{-2}$ and 16000 mJ $cm^{-2}$.

Fig. 5 shows elastic (Hookean) modulus values as determined based in the 10-15% applied strain range and also as determined based in the 1-2% applied strain range, for regions subjected to different UV doses.

Fig. 6 shows the effect of UV dose on elastic modulus (E). Also illustrated is the effect of the curing conditions (here 60°C cure for times of 16, 90 or 112 hours). E is determined based on 10-15% applied strain range.

Fig. 7 shows the effect of curing time on the elastic modulus (E) of a region of a sample having a uniform UV dose (8000 mJ $cm^{-2}$, corresponding to a 200 seconds exposure). E is determined based on 10-15% applied strain range. It is noted here that the results correspond reasonably well with the ageing results presented in Fig. 4 of Eddington et al 2003. This is further illustrated in Fig. 8, showing a comparison of the behaviour of E with ageing (60°C cure for various amounts of time). E is determined based on 10-15% strain. The stability of PP-PDMS (photo-patternable PDMS) is comparable to that of conventional PDMS. This is still further illustrated by Fig. 9, which shows the effect of curing time on E for PP-PDMS which is either UV-exposed or not UV-exposed, in comparison with conventional PDMS. E is determined based on 1-2% strain.

It is of interest to consider the use of elastically deformable sheets according to embodiments of the invention as substrates for stretchable electronic devices and circuits. Such devices are preferably able to withstand strains >>1% without electrical failure.

The manufacture of stretchable electronic devices requires the processing of active components such as transistors or the integration of commercial integrated circuits on elastomeric substrates (such as PDMS). Additionally or alternatively, it is possible to encapsulate suitable electronic devices in an elastically deformable sheet.

Because the materials used to fabricate the individual electronic components cannot withstand large deformations, a mechanical architecture must be implemented to guarantee that the materials do not break.

To overcome this issue the fragile individual electronic components can be mechanically shielded by a carefully designed architecture of rigid islands, e.g. formed of diamondlike carbon (DLC), tinned silicon ribbons or polyimide, to decouple the strain from the actual electronic component fabricated on top and thus ensure continuous electrical operation. The electronic components are subsequently connected to each other via stretchable or deformable electrically conductive interconnects.

However, at the interface between the rigid islands and the elastomeric substrate, there is a large concentration of mechanical stress and resulting strain, which the inventors consider to be the main failure point of the connecting stretchable interconnects. The present inventors have found that, using the photo graded?-mechanical properties of photo-patternable PDMS, the interface stress between the elastomeric substrate and rigid platform can be reduced.

Fig. 11 shows a schematic cross section view of a rigid platform 102 (island) formed on an elastically deformable elastomeric substrate 104. The elastic modulus of the elastomeric substrate is uniform. A stretchable conductor 106 is formed over the substrate and the rigid platform. When the elastomeric substrate is stretched, a stress concentration (indicated by reference numeral 108) occurs at the meeting point of the edge of the rigid platform and the elastomeric substrate. Therefore failure (e.g. of the stretchable conductor) is likely to occur at this point.

Fig. 12 illustrates a use of an elastically deformable elastomeric substrate according to an embodiment of the invention. A first region 110 of relatively high E is formed in the substrate in register with the rigid platform. The bulk 118 of the substrate formed the second region of relatively low E. Between the first and second regions are formed further regions 112, 114, 116 of gradually decreasing E, forming a zone of gradually decreasing E. This has

the effect of spreading out stress concentrations, schematically indicated by 120, thereby reducing the maximum stress concentration and reducing the risk of failure.

Figs. 13-15 show cross sectional strain maps derived from COMSOL models of the principal strain at the interface from a 1 μm thick island attached to the surface of a 100 μm thick PDMS substrate. In each case a strain of 0.2 (20%) is applied to the PDMS substrate. Poisson's ratio is assumed to be constant at 0.5. This also applies to Fig. 16.

The original data were in the form of maps showing the amount of strain in the form of false colour. Figs. 13-15 are re-drawn, showing simple contours of equal strain in the substrate material, the value of the strain at each contour line being labelled.

The calculations that form the basis for the results shown in Figs. 13-15 are based on a linear (Hookean) model of the polymer. For this reason, the values shown in Figs. 13-15 are first order approximations only. More accurate modelling relies on a non-linear model e.g neo-Hookean or Mooney-Rivlin, of the polymer. However, it is considered that the trends shown in Figs. 13-15 are generally correct and so these drawings are retained for their schematic illustration of these trends.

In Fig. 13, the elastic modulus of the entire substrate is kept constant, at 1 MPa. In Fig. 14 the elastic modulus of the substrate is allowed to change at a distance of 10 μm from the edge of the island 30, so that the first region A (under the rigid island) has a elastic modulus of 3 MPa and the second region B has a elastic modulus of 1 MPa. In Fig. 15 the elastic modulus of the substrate is allowed to change at a distance of 10 μm from the edge of the island, and then again at a distance of 30 μm from the edge of the island, so that the first region A' (under the rigid island) has a elastic modulus of 3 MPa, a third region C' adjacent the first region has a elastic modulus of 2 MPa and the second region B' has a elastic modulus of 1 MPa.

As mentioned above, the quantitative data on which Figs. 13-15 are based is not considered to be absolutely accurate, in view of the linear model used for the polymer. However, the following discussion is retained for its indication of the trend of the effect of the invention.

These results shown in Figs. 13-15 show that the localised maximum strain is reduced from 0.79 (4x the strain applied to the substrate) to 0.27 (1.35 x the applied strain) at the interface between the rigid island and the substrate. The transition strain may be further reduced by optimising the geometry, positioning and modulus gradient of the mechanical shielding substrate. The gradient of mechanical properties can be achieved with a single exposure by using binary or grey tone photo-masks to control the amount of UV exposure to each area of the substrate.

The present inventors have found that a small change in E of 0.1MPa from the first region to the second region (E (first region) = 3MPa, E (second region) = 2.9MPa) gives a drop of 2% maximum principal strain. Ideally the aim is to prevent stretching of the first region at all, in order to protect any strain-sensitive device that is mounted at the first region. However, this is not possible at present. Instead, the preferred embodiments of the invention allows the reduction (or even minimisation) of peak strain, in order to protect electrical interconnects running off from the first region.

Fig. 16 shows results of simulation as in Figs. 13-15, showing a variation in the maximum principal strain for a change in E of the first, second and third regions of the substrate. Throughout the simulations the first region of the substrate (where the rigid island is) is kept at E = 3MPa, whilst E of the third region is varied along with E of the second region (bulk material). One set of data points requires that E of the third region is 2.5 MPa. Another set of data points requires that E of the third region is 2 MPa. Another set of data points requires that E of the third region is 1.5 MPa. The final set of data points requires that E of the third region is the same as E of the bulk material.

The results from Figs. 13-15 show that above E(bulk material) =1 MPa the highest principal strain is at one of the interfaces between the change in modulus of material. Below this value

the maximum strain is located away from the interface on the bulk material itself. This can be seen on Figs. 13-15 as a local minimum principal strain when E(bulk material) = 1MPa. This is also illustrated in Fig. 17, where E(1) is E for the first region (=3 MPa), E(2) is E for the second region (bulk material) and E(3) is E for the third region. Reference numeral 200 shows the locations of maxiumum principal strain when E (bulk) > 1MPa. Reference numeral 202 shows the location of maximum principal strain when E (bulk) < 1MPa.

In respect of suitable thickness for the elastically deformable sheets according to the invention, the inventors have considered B Ma et al 2007 [B Ma, X Zhou, G Wang, Z Dai, J Qin, B Lin "A hybrid microwave device with a thin PDMS membrane on the detection window for UV absorbance detection" Electrophoresis 2007, 28, 2474-2477]. This document discloses that a PDMS membrane of thickness of about 100μm has high UV transmittance. A PDMS membrane 1000μm thick still has about 85% UV transmittance at UV wavelength of 300 nm. Therefore it is considered that embodiments of the present invention can have elastically deformable sheet thickness of up to 1 mm, and possibly greater (e.g. up to 2 mm, up to 3 mm, up to 4 mm, and up to 5 mm is possible, where necessary activating the activatable cross-linking controlling component from the upper and lower surface of the sheet.

Since the initial filing date of this disclosure, the present inventors have published additional data relating to the present invention. This work has been published in Cotton et al (2011) [DPJ Cotton, A Popel, IM Graz and SP Lacour "Photopatterning the mechanical properties of polydimethylsiloxane films" Journal of Applied Physics 109, 054905 (2011)] and in Graz et al (2011) [IM Graz, DPJ Cotton, A Robinson, SP Lacour "Silicone substrate with *in situ* strain relief for stretchable thin-film transistors" Applied Physics Letters 98, 124101 (2011)]. The work published in Cotton et al (2011) and Graz et al (2011) discloses numerical data obtained by modelling the polymer films using the non-linear Mooney-Rivlin model. As a result, the data disclosed in those publications is considered to be more accurate in absolute terms than the initial data presented in the present disclosure.

The content of Cotton et al (2011) and Graz et al (2011) are hereby incorporated by reference in their entirety in view of their further demonstration of the technical effect of preferred embodiments of the present invention. Specific parts of these references of particular relevance are discussed below.

Specifically, Fig. 3 of Cotton et al (2011) corresponds to Fig. 4 of the present disclosure. Fig 4 of Cotton et al (2011) discloses stress as a function of applied stretch for samples exposed to specific uv fluxes and baked for different amounts of time. Thus, Fig 4 of Cotton et al (2011) corresponds to Figs. 6-9 of the present disclosure.

Cotton et al (2011) also discloses technical results indicating the change in electrical resistance of an interconnect patterned on a uniform modulus silicone substrate compared with a similar interconnect patterned on a graded silicone substrate according to an embodiment of the present invention. Fig. 7 of Cotton et al (2011) shows that the interconnect formed on the graded substrate has a much more stable resistance response after mechanical cycling, considered to be due to the more suitable strain distribution afforded by the graded substrate.

Graz et al (2011) discloses the formation of stretchable thin film transistors (TFTs) and stretchable interconnects on silicone substrates. Of particular interest is Fig. 4 of Graz et al (2011), which shows the results of finite element modelling of how the first principal strain varies with position in (a) a uniform silicone substrate and (b) a graded modulus silicone substrate. The results are shown in colour in Graz et al (2011) and are particularly striking. Fig. 4 of Graz et al (2011) therefore corresponds to Figs. 13-16 of the present disclosure.

Preferred embodiments of the invention have been described by way of example. Modifications of these embodiments, further embodiments and modifications thereof will be apparent to the skilled person and as such are within the scope of the invention.

## CLAIMS

1. An elastically deformable sheet formed from a cross-linkable polymer, the sheet having a first region having a first elastic modulus value and a second region having a second elastic modulus value, the first and second elastic modulus values being different, the ratio between the first and second elastic modulus values being at least 1.1, wherein the first and second regions of the sheet have substantially the same composition, the difference in the first and second elastic modulus values being provided by a difference in the degree of cross-linking of the cross-linkable polymer at the first and second regions.

2. An elastically deformable sheet according to claim 1 wherein the ratio between the first and second elastic modulus values is at least 1.5.

3. An elastically deformable sheet according to claim 1 or claim 2 wherein the ratio between the first and second elastic modulus values is at most 1000.

4. An elastically deformable sheet according to any one of claims 1 to 3 further including a third region having a third elastic modulus value, different to the first and second elastic modulus values, wherein the ratio between the first and third elastic modulus values and the ratio between the second and third elastic modulus values are independently at least 1.05 or at most 0.95.

5. An elastically deformable sheet according to claim 4 wherein the third region has substantially the same composition as the first and second regions of the sheet, the differences in the first, second and third elastic modulus values being provided by a difference in the degree of cross-linking of the cross-linkable polymer at the first, second and third regions.

6. An elastically deformable sheet according to any one of claims 1 to 5 wherein the elastically deformable sheet has at least one zone across which the elastic modulus value for

the material of the sheet varies gradually, the zone incorporating at least part of the first and second regions, the composition of the zone being substantially uniform.

7. An elastically deformable sheet according to any one of claims 1 to 6 wherein the first and second regions of the sheet have substantially the same thickness, or substantially the same thickness variation.

8. An elastically deformable sheet according to any one of claims 1 to 7 formed from an elastomeric polymer such as a silicone polymer (polysiloxane).

9. A method of manufacturing an elastically deformable sheet according to any one of claims 1 to 8, the method including providing an uncured sheet of:

a matrix material either formed of a monomer or pre-polymer capable of forming a polymer, or formed of a polymer, the polymer being capable of being cross-linked;

a cross-linking component; and

an activatable cross-linking controlling component, wherein the activatable cross-linking controlling component is capable of affecting the ability of the cross-linking component to cross-link the matrix material,

the method further including the steps:

selectively activating the activatable cross-linking controlling component in at least a second region of the uncured sheet; and

curing the sheet to effect cross-linking, thereby to form the elastically deformable sheet having said first and second regions with different elastic modulus values.

10. A method according to claim 9 wherein the selective activation of the activatable cross-linking controlling component is carried out by selectively controlling an irradiation flux and the first and/or second regions.

11. A method according to claim 10 wherein the irradiation flux is electromagnetic radiation (e.g. ultra violet radiation, visible light or infra red radiation) or a particle beam (e.g. electron beam, ion beam or alpha particle beam).

12. A method according to any one of claims 9 to 11 wherein the sheet is subsequently cured at elevated temperature.

13. A method of manufacturing an elastically deformable sheet according to any one of claims 1 to 8, the method including providing an uncured sheet of:

a matrix material either formed of a monomer or pre-polymer capable of forming a polymer, or formed of a polymer, the polymer being capable of being cross-linked; and

an activatable cross-linking component, wherein the activatable cross-linking component is capable of being activated to cross-link the matrix material,

the method further including the steps:

selectively activating the activatable cross-linking component in at least a first region of the uncured sheet; and

curing the sheet to effect cross-linking, thereby to form the elastically deformable sheet having said first and second regions with different elastic modulus values.

14. Use of an elastically deformable sheet according to any one of claim 1 to 8 as a substrate for one or more electronic components.

15. An electronic device including a plurality of individual electronic components, the individual electronic components being mounted on an elastically deformable sheet according to any one of claims 1 to 8, at respective first regions of the elastically deformable sheet, elastically deformable electrical interconnects being formed between the individual electronic components.

16. A device according to claim 15 wherein the elastically deformable sheet includes an array of said first regions.

17. A device according to claim 15 or claim 16 wherein each individual electronic component is mounted on the elastically deformable sheet via a mounting layer, the mounting

layer being formed in register with the first region, the mounting layer being formed of a material having a elastic modulus value that is at least 10 times the elastic modulus value of the first region.

5

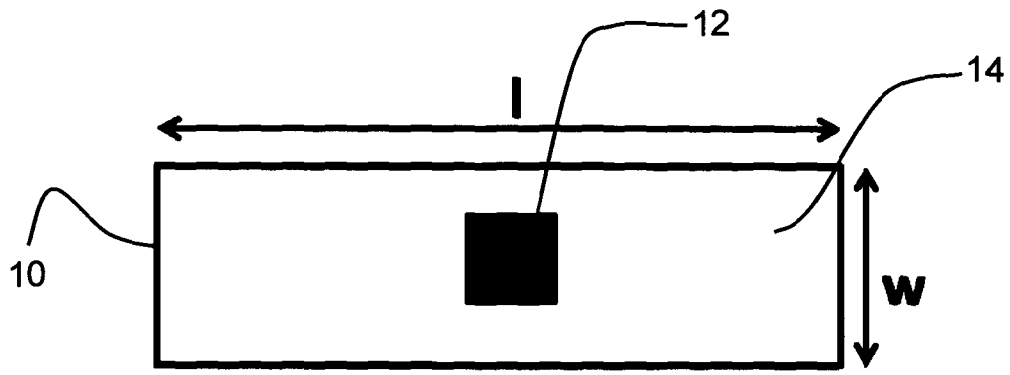



Fig. 1

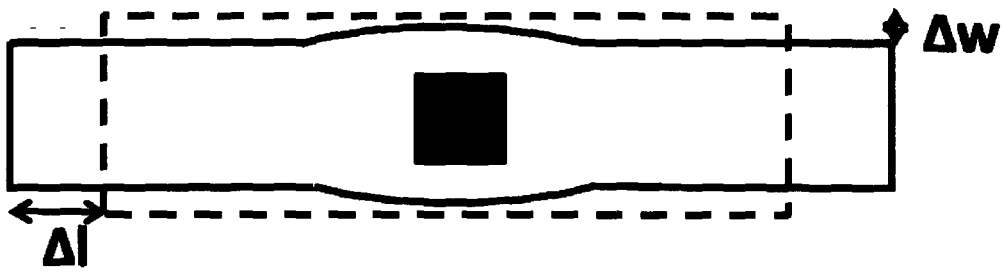



Fig. 2

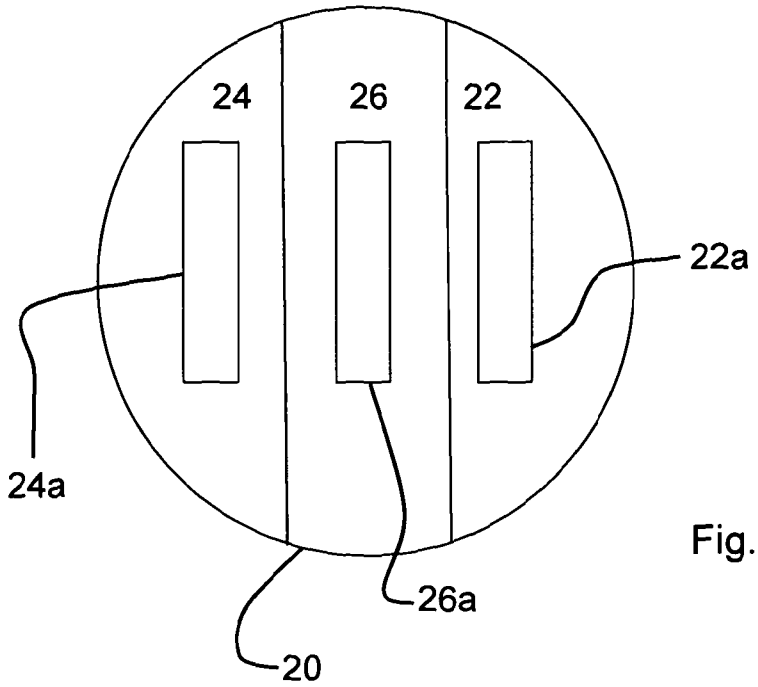



Fig. 3

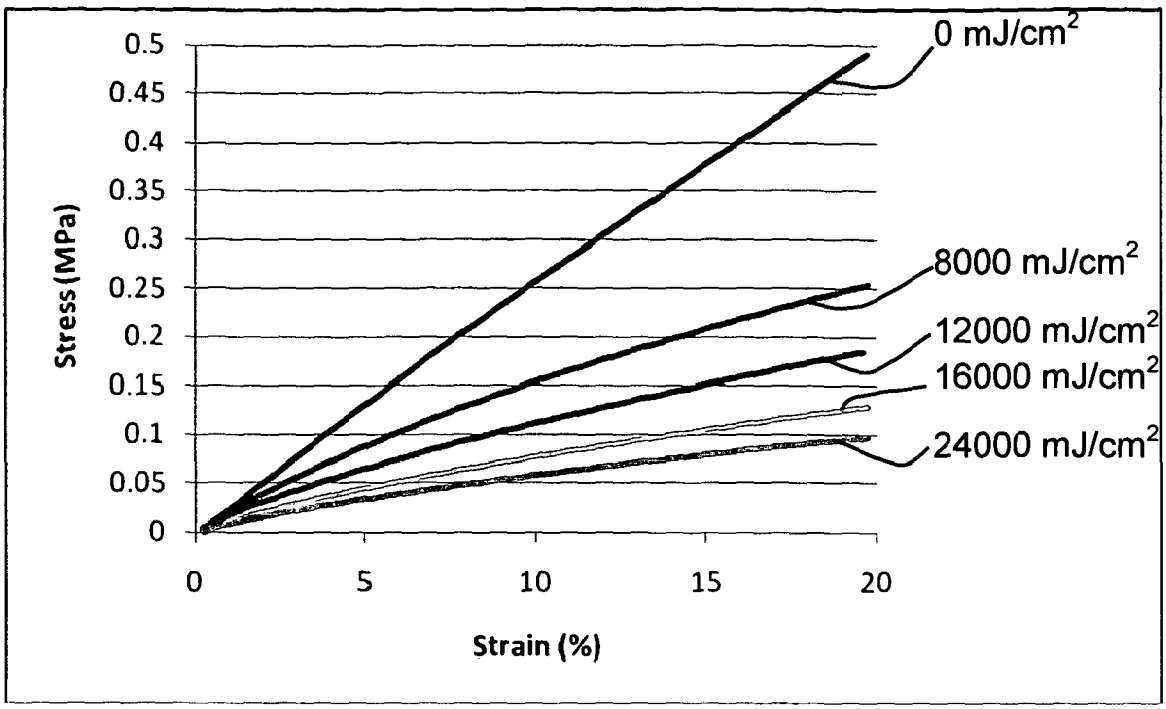

0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Stress (MPa)
0
5
10
15
20
Strain (%)
0 mJ/cm2
8000 mJ/cm2
12000 mJ/cm2
16000 mJ/cm2
24000 mJ/cm2

Fig. 4

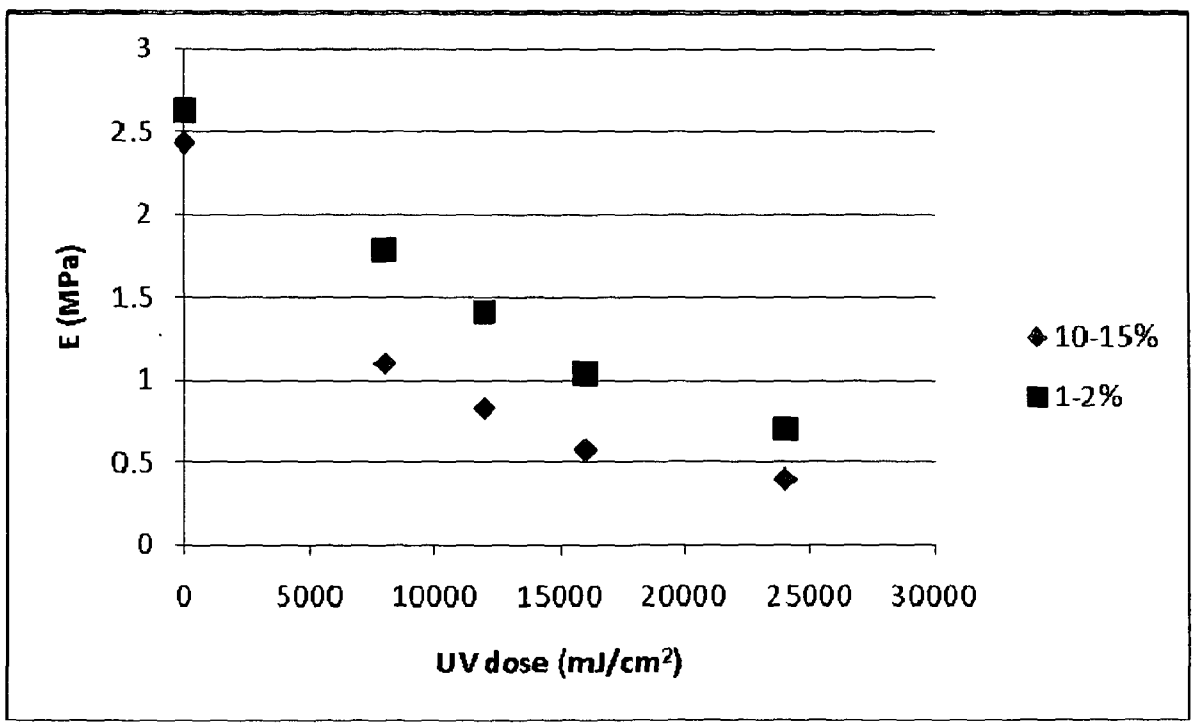

3
2.5
2
1.5
1
0.5
0
E (MPa)
0
5000
10000
15000
20000
25000
30000
UV dose (mJ/cm2)
10-15%
1-2%

Fig. 5

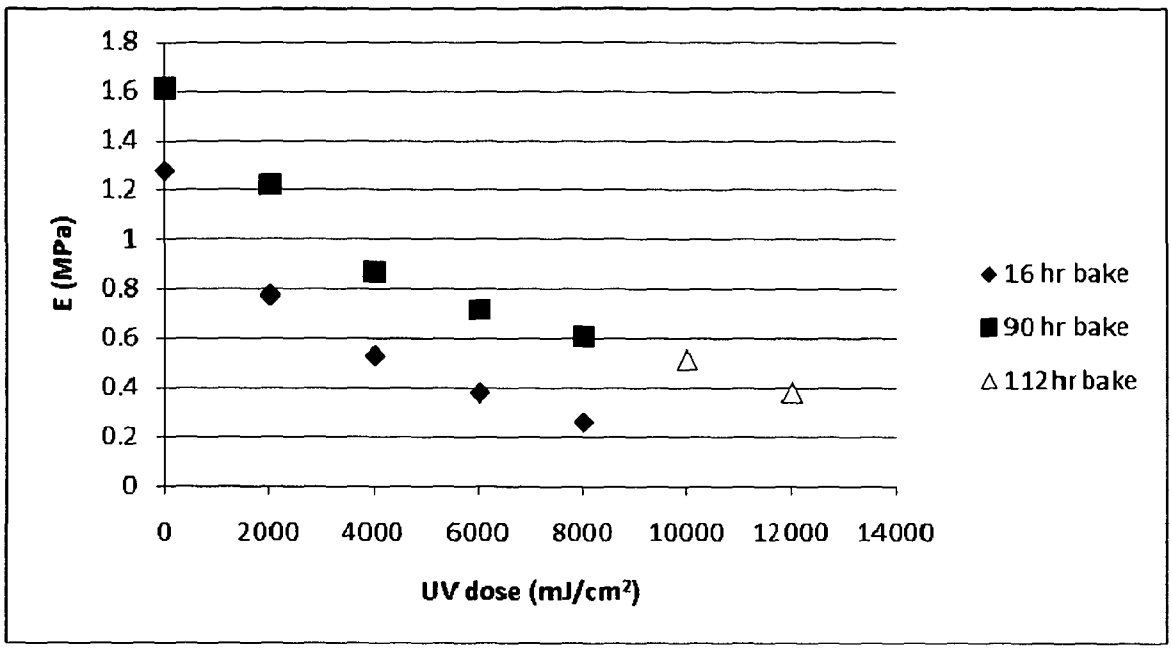

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
E (MPa)
0
2000
4000
6000
8000
10000
12000
14000
UV dose (mJ/cm²)
16 hr bake
90 hr bake
112hr bake

Fig. 6

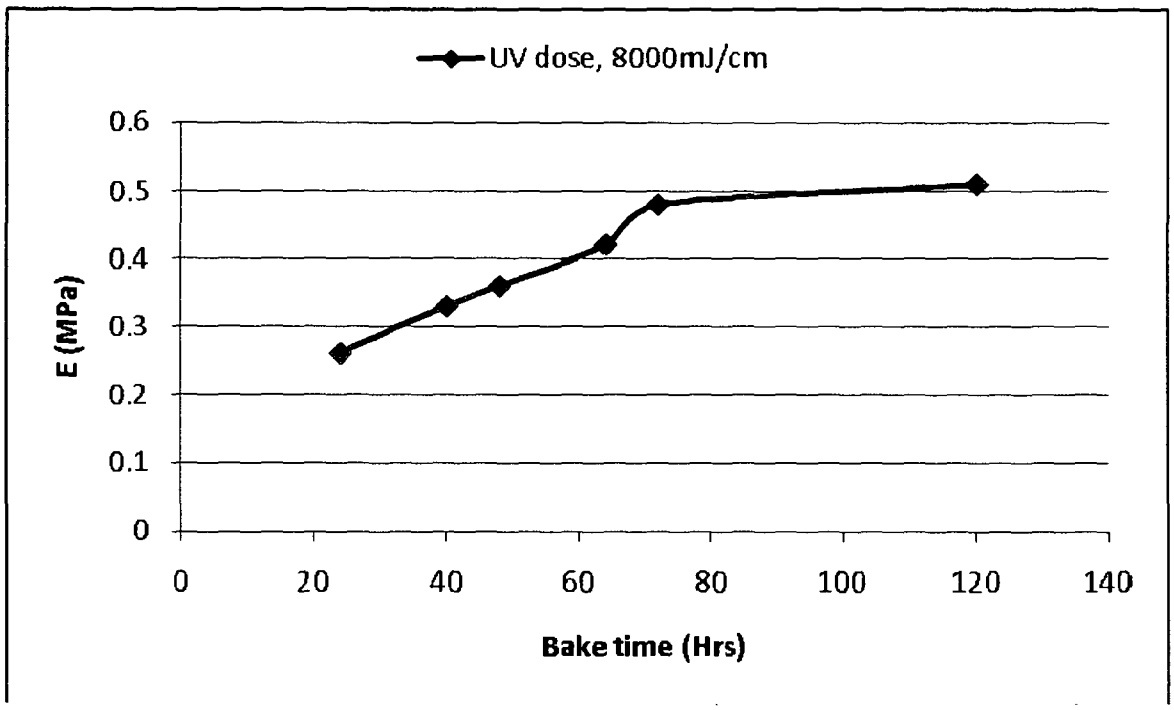

UV dose, 8000mJ/cm
0.6
0.5
0.4
0.3
0.2
0.1
0
E (MPa)
0
20
40
60
80
100
120
140
Bake time (Hrs)

Fig. 7

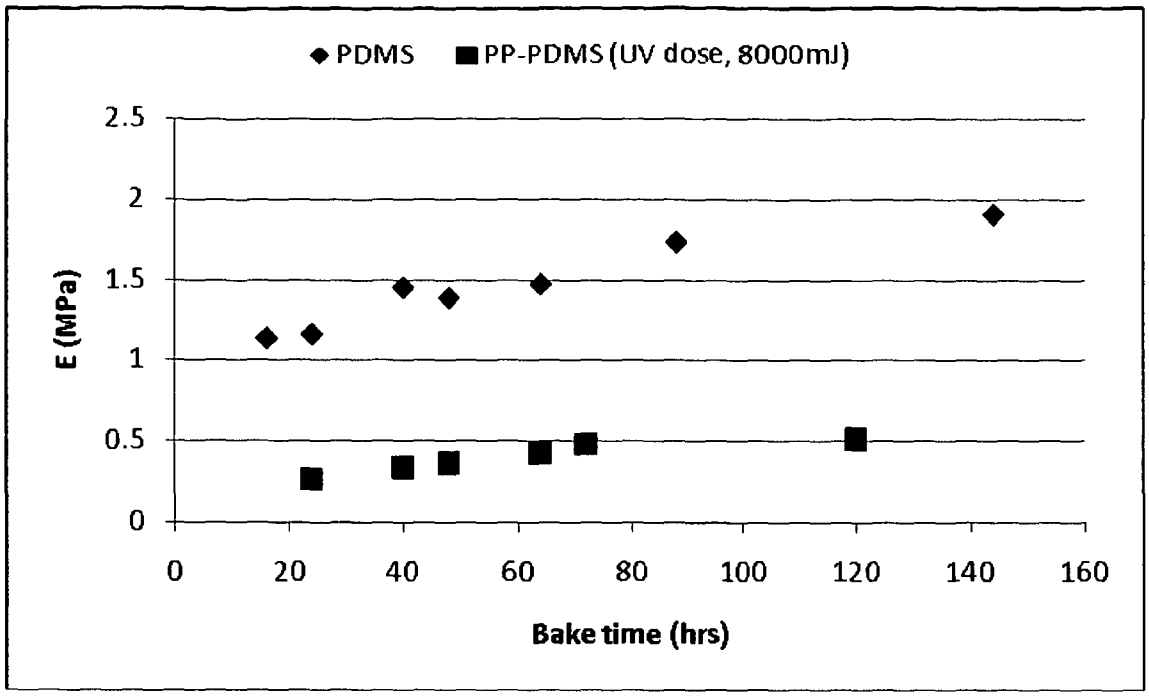

PDMS
PP-PDMS (UV dose, 8000mJ)
E (MPa)
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
160
Bake time (hrs)

Fig. 8

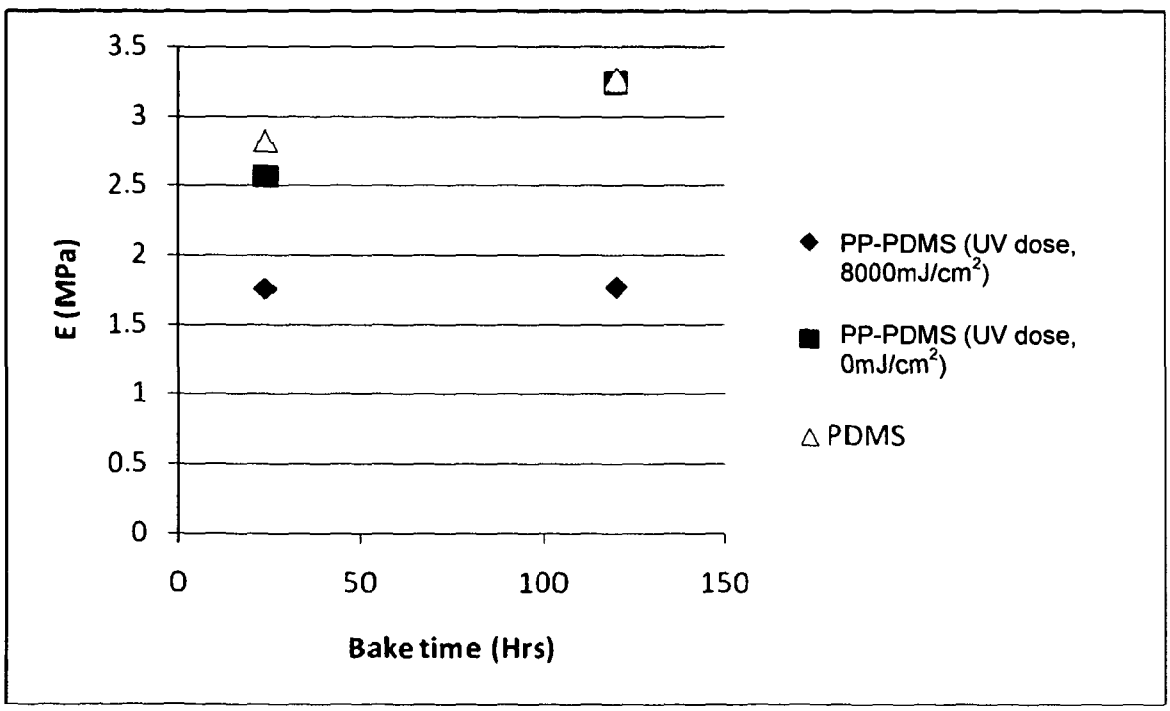

E (MPa)
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
Bake time (Hrs)
PP-PDMS (UV dose, 8000mJ/cm2)
PP-PDMS (UV dose, 0mJ/cm2)
PDMS

Fig. 9

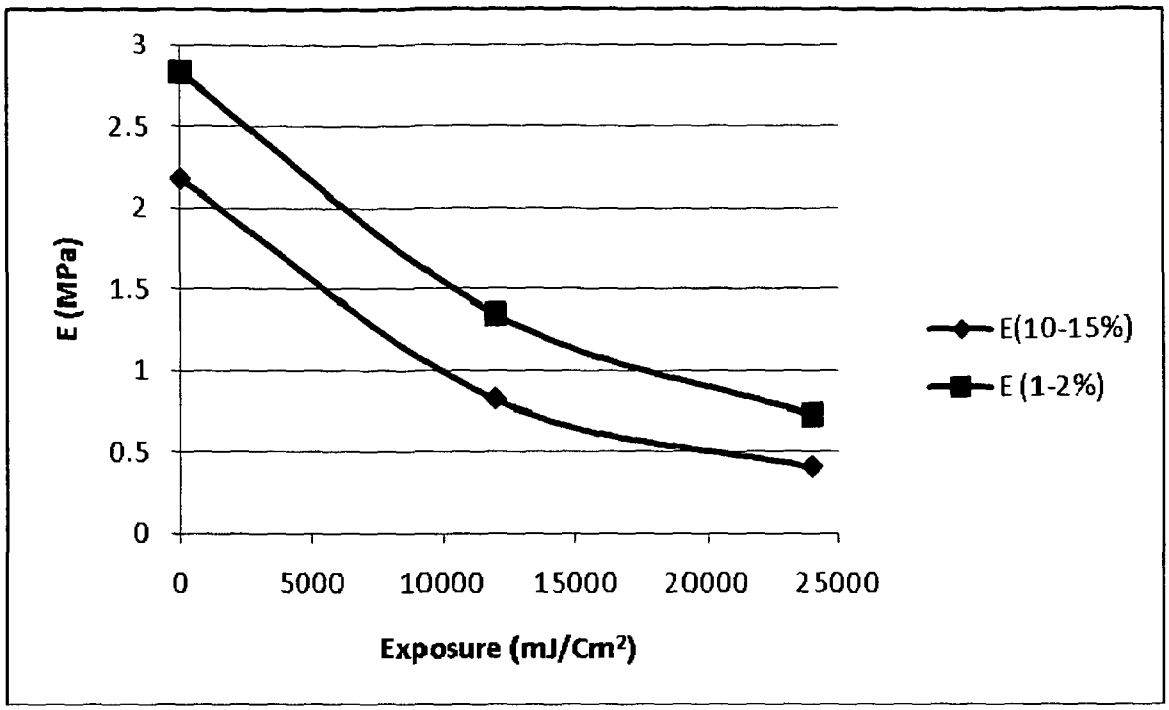

3
2.5
2
1.5
1
0.5
0
E (MPa)
0
5000
10000
15000
20000
25000
Exposure (mJ/Cm²)
E(10-15%)
E (1-2%)

Fig. 10

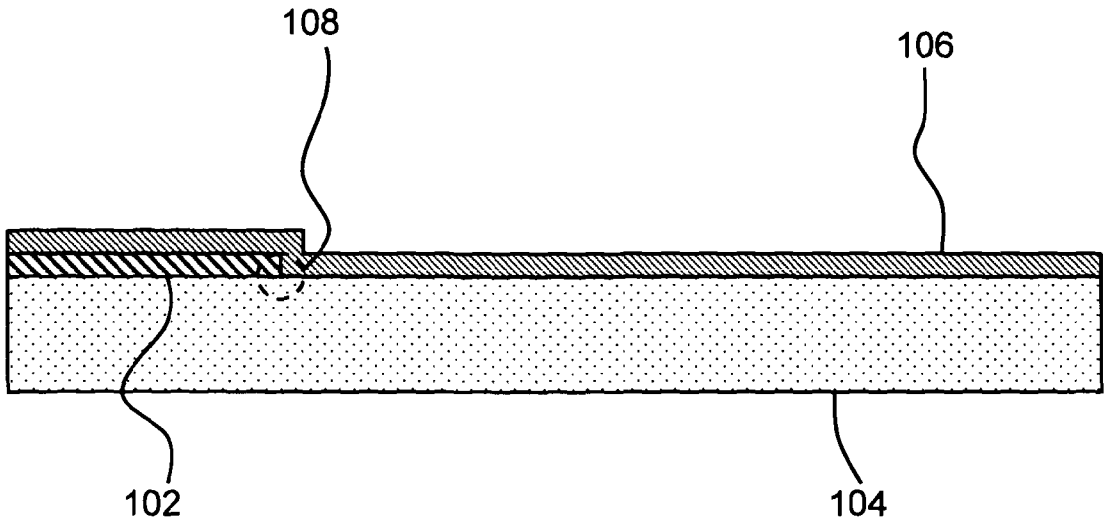



Fig. 11

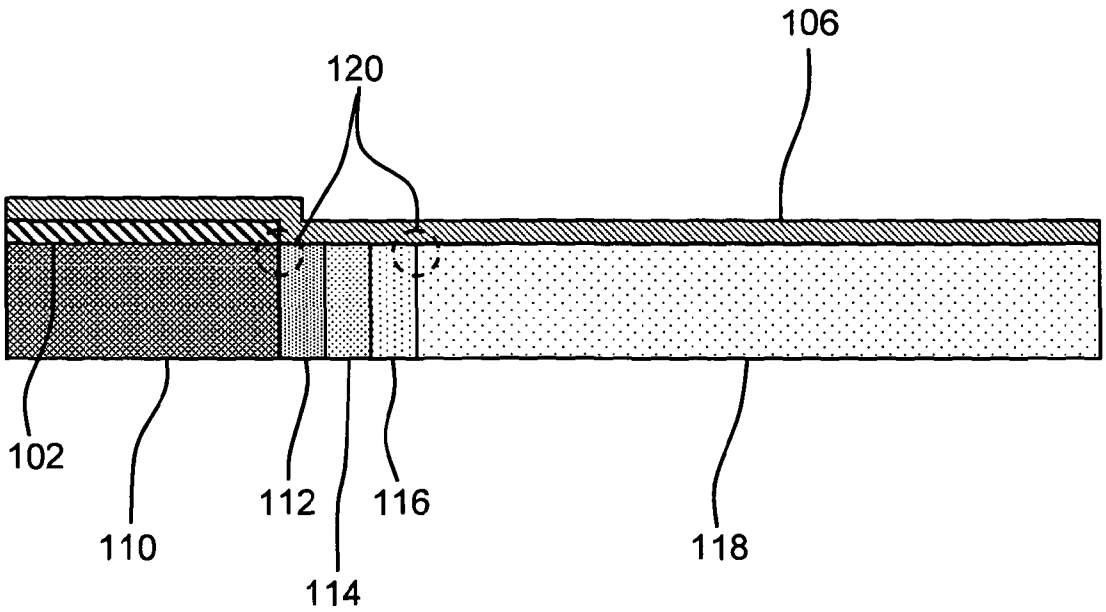



Fig. 12

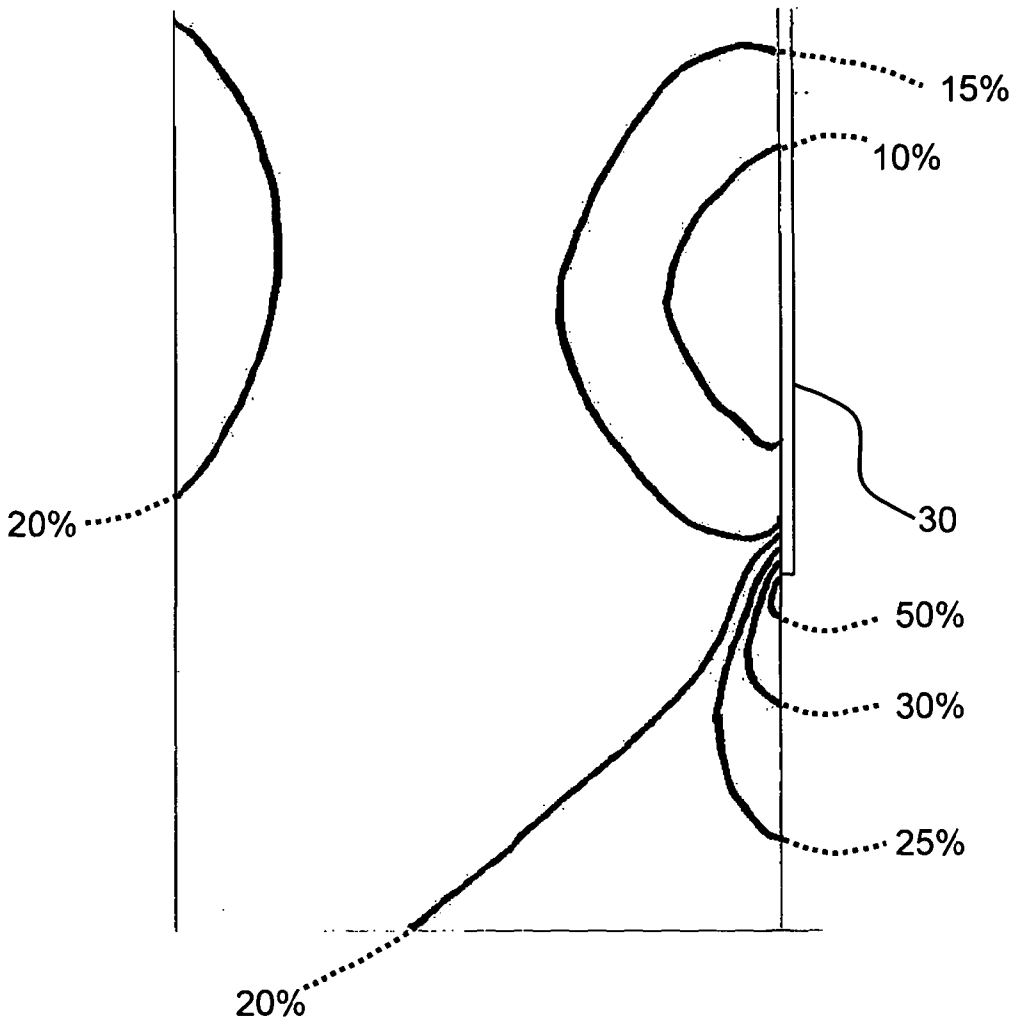



Fig. 13

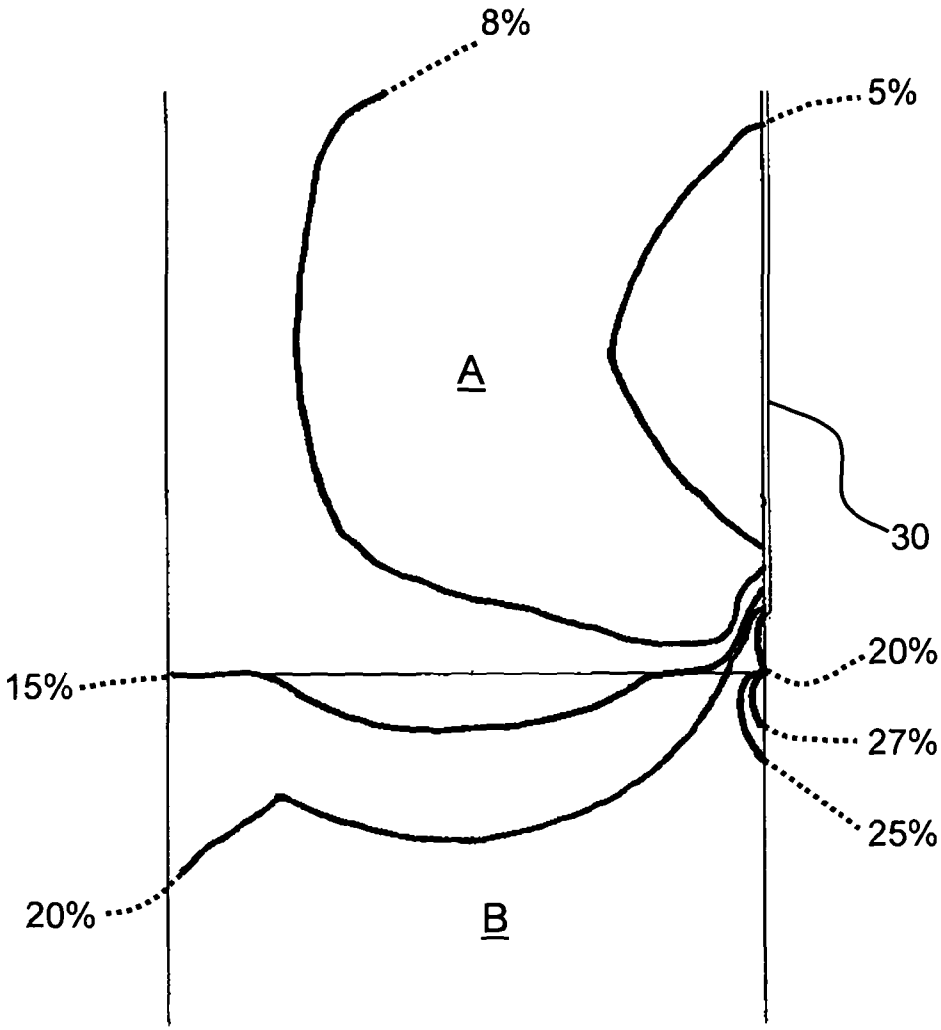



Fig. 14

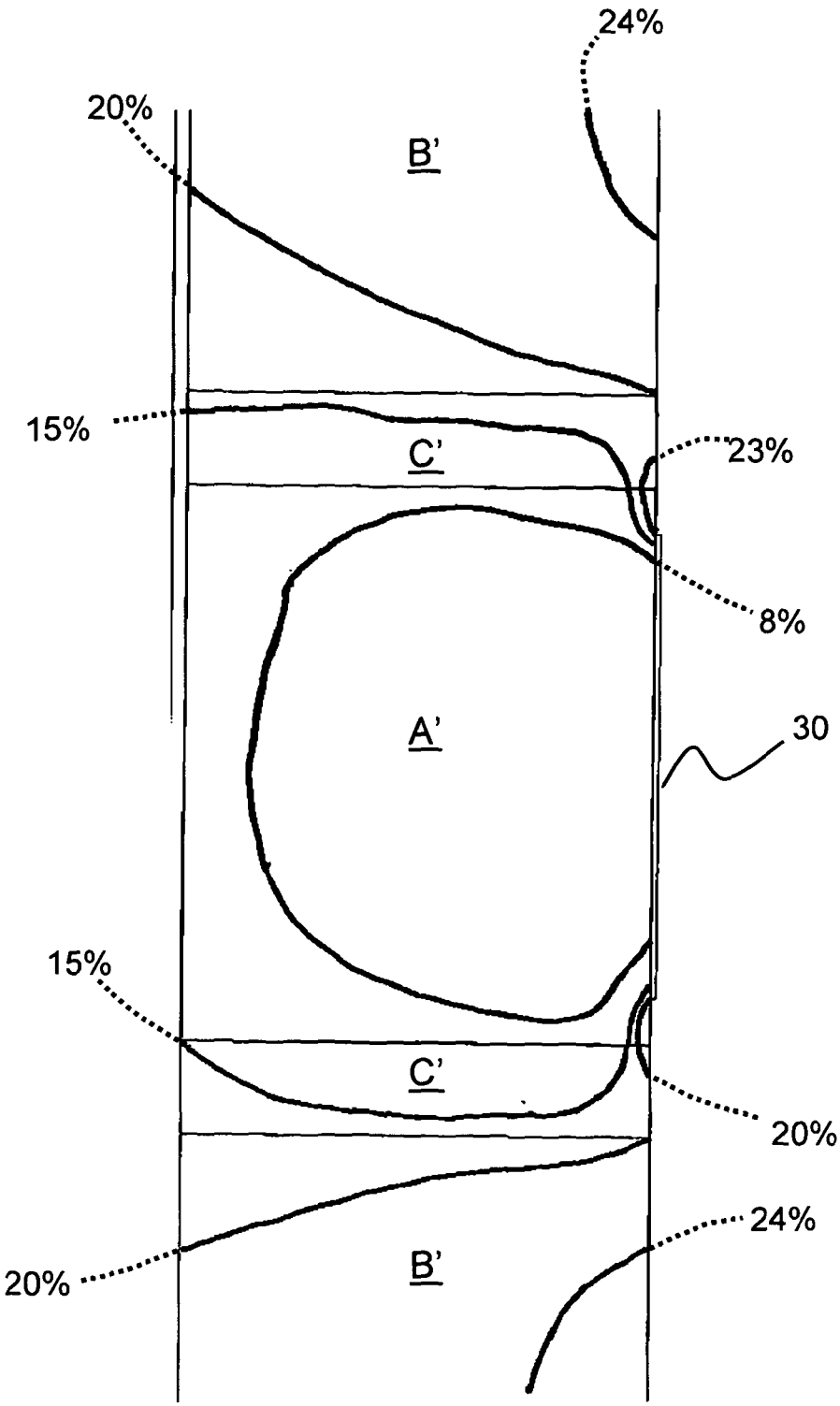



Fig. 15

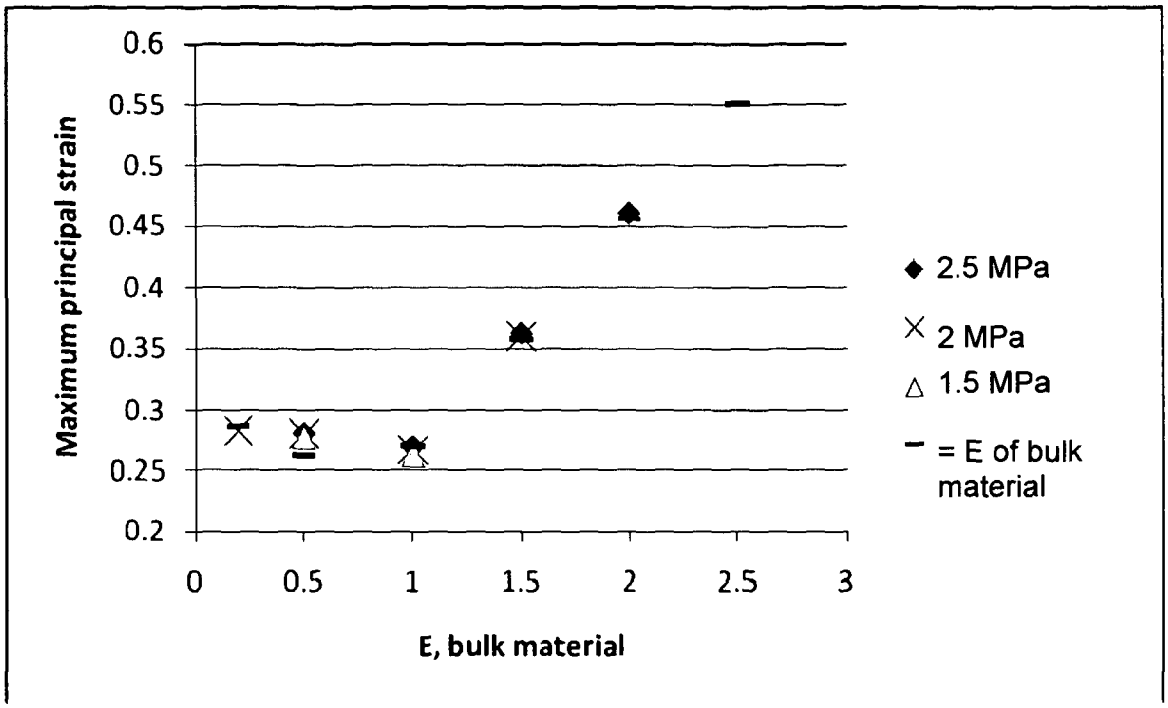

Maximum principal strain
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0
0.5
1
1.5
2
2.5
3
E, bulk material
2.5 MPa
2 MPa
1.5 MPa
= E of bulk material

Fig. 16

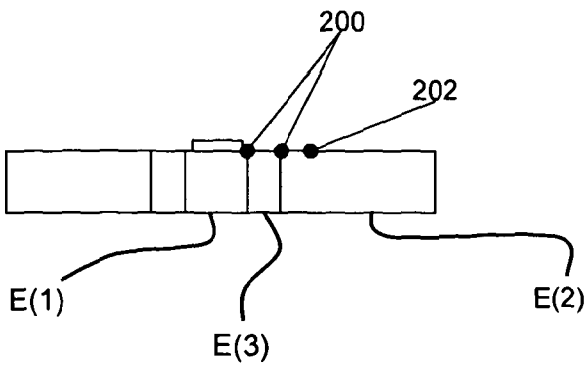

200
202
E(1)
E(3)
E(2)

Fig. 17

# INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/000552

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08J5/18 C08L83/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08J C08L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, CHEM ABS Data, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2007/104588 A1 (BENECKE KALIKO AG [DE]; BUEHRING JUERGEN [DE]) 20 September 2007 (2007-09-20) abstract in particular claims 1,7; page 11 - page 13; claims 1-13 | 1-13 |
| A | WO 2009/111641 A1 (UNIV ILLINOIS [US]; ROGERS JOHN A [US]; HUANG YONGGANG [US]; KO HEUNG) 11 September 2009 (2009-09-11) cited in the application the whole document | 1-17 |

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 19 August 2011 | 01/09/2011 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Jung, Andreas |

3

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| A | J. A. ROGERS ET AL: "Materials and Mechanics for Stretchable Electronics", SCIENCE, vol. 327, no. 5973, 26 March 2010 (2010-03-26), pages 1603-1607, XP55005234, ISSN: 0036-8075, DOI: 10.1126/science.1182383 cited in the application the whole document | 1-17 |

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Information on patent family members

International application No
PCT/GB2011/000552

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
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