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2D Digital Laser printing of Kirigami-inspired 3D Strain Sensor

Ratul Kumar Biswas, Nazar Farid, Gerard O'Connor, Patricia Scully*.

Abstract: Flat Polyimide (PI) sheeting was processed using two femtosecond laser settings:

1. To carbonize strain sensitive tracks.
2. To cut around sensing elements to form a topological shape that encased 3D body parts.

Hence a Kirigami-inspired sensor was created in 2D to measure 3D shapes.

Femtosecond Laser-Polyimide Interaction:

Laser carbonization with 1030 nm 550 fs laser at scan speed 2-3 nm, power 0.24-0.28 W, at repetition rate 200 kHz occurs due to heat accumulation and the low incubation coefficient of 0.21 in this regime. Laser ablation occurs due to multiphoton absorption at 1.72-2.51 W, at f=200 kHz, and scan speed 200-300 mm/s. The incubation coefficient in this regime was 0.66 which didn't create any carbonization causing a clean ablation.

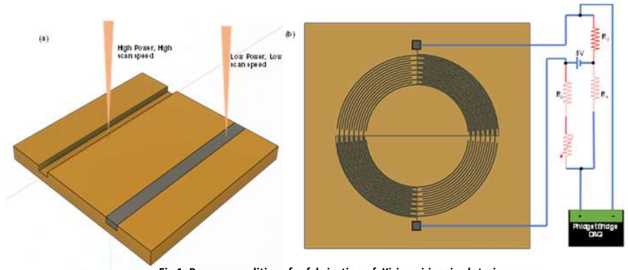

Fig 1. Process conditions for fabrication of Kirigami-inspired strain-sensor.

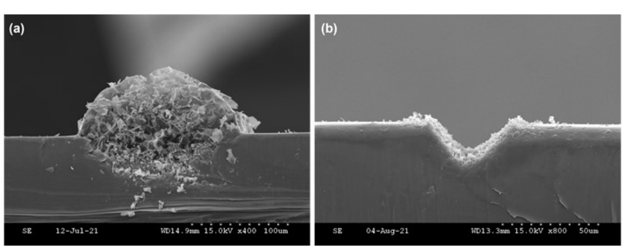

Fig 2. Cross-sectional SEM of (a) LIG at 0.26 W, 2 mm/s, and (b) ablated PI at 2.12 W, 200 mm/s.

Sensing action of Kirigami vs Planar sensor:

The Gauge factor of a single track of LIG was 96.97. Kirigami design showed increased sensitivity to bending of knee measure by placing the sensor under the knee-cap. The Kirigami sensor showed a change in the output voltage by 10.7±1.4 % upon knee-bending as compared to 3.0±0.7 % in planar sensor due to enhanced stress accumulation (by order~ 10^2 N/m^2) and conformal fitting on body joints.

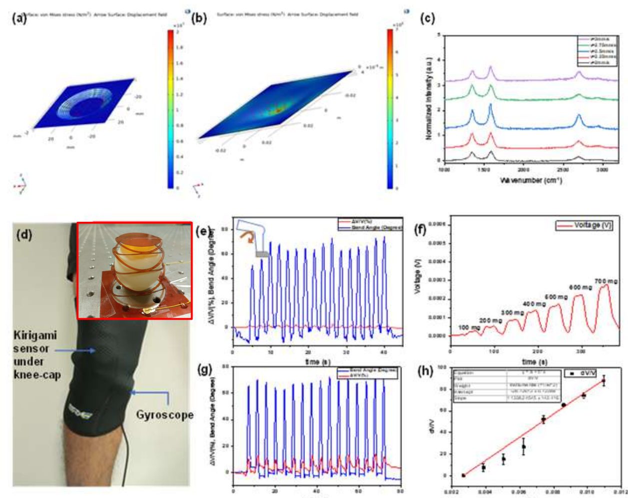

Fig 3. Stress distribution upon 500 mg placed at centre of (a) Kirigami sensor; (b) Planar sensor; (c) Raman spectra of LIG drawn at 0.24 W at scan speeds 2-3 mm/s; (d) Kirigami inspired strain sensor used under knee-cap along with gyroscope; (e,g) Relative change in voltage upon bending of knee from the planar sensor; (f) Change in Phidget Bridge voltage upon loading of 100-700 mg; (g) Gauge Factor measurement from *ΔV/V* vs strain.

Conclusion

- Femtosecond laser used in 2 regimes: to create sensor tracks & to cut out sensitive elements.
- Carbonization created sensor elements & laser ablation cut shapes around sensor tracks.
- Kirigami-inspired strain sensor sensed topology of 3D spatial structure but created in 2D space.
- Carbonization: heat accumulation process. Cutting-ablation: multiphoton absorption.
- Kirigami design demonstrated improved better response to knee-bending, compared to planar sensor. Processing is digitally controlled, capable of scaling up, & can be used for soft-robotics.

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*Dr Patricia Scully, Polymer Sensors and Devices Research Group, Physics Unit, School of Natural Sciences, University of Galway. H91 TK33

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