Strain gauge properties of Pd^{+}-ion implanted polymers

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Supporting Information

Deviation s, i.e. the beam deflection, as a function of applied force F

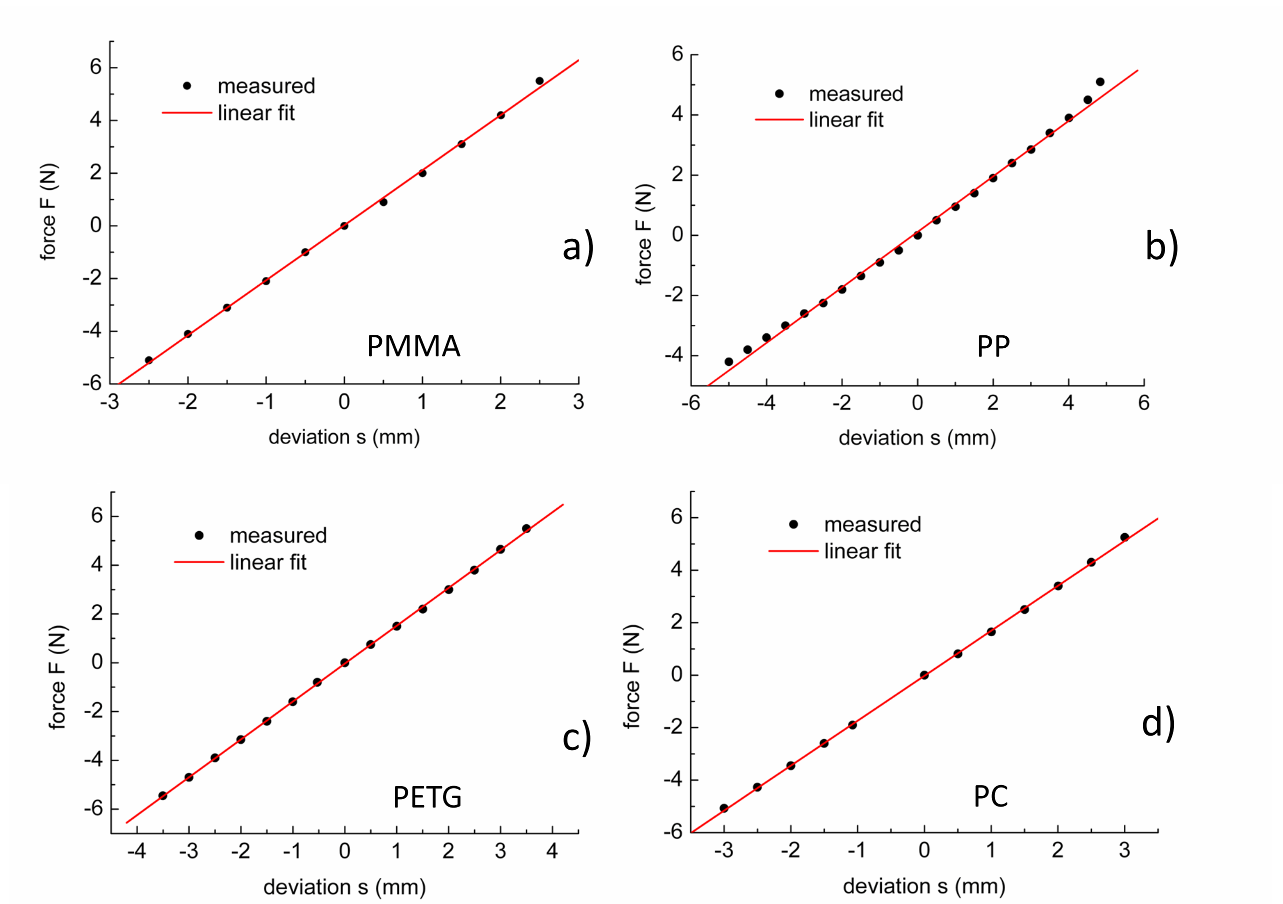

Fig.S1 Experimental data points of the beam deflection, deviation *s*, as a function of the force *F* applied to the sample's free end; a linear relationship (red lines) is obtained for all the samples. For all samples the same magnitude of force has been applied, ranging from -6N to +6N; at *F*=0N no deviation, beam deflection, was measured, i.e. *s*=0.

Electrical resistance, R_s, as a function of the deviation s (slab bending or beam deflection)

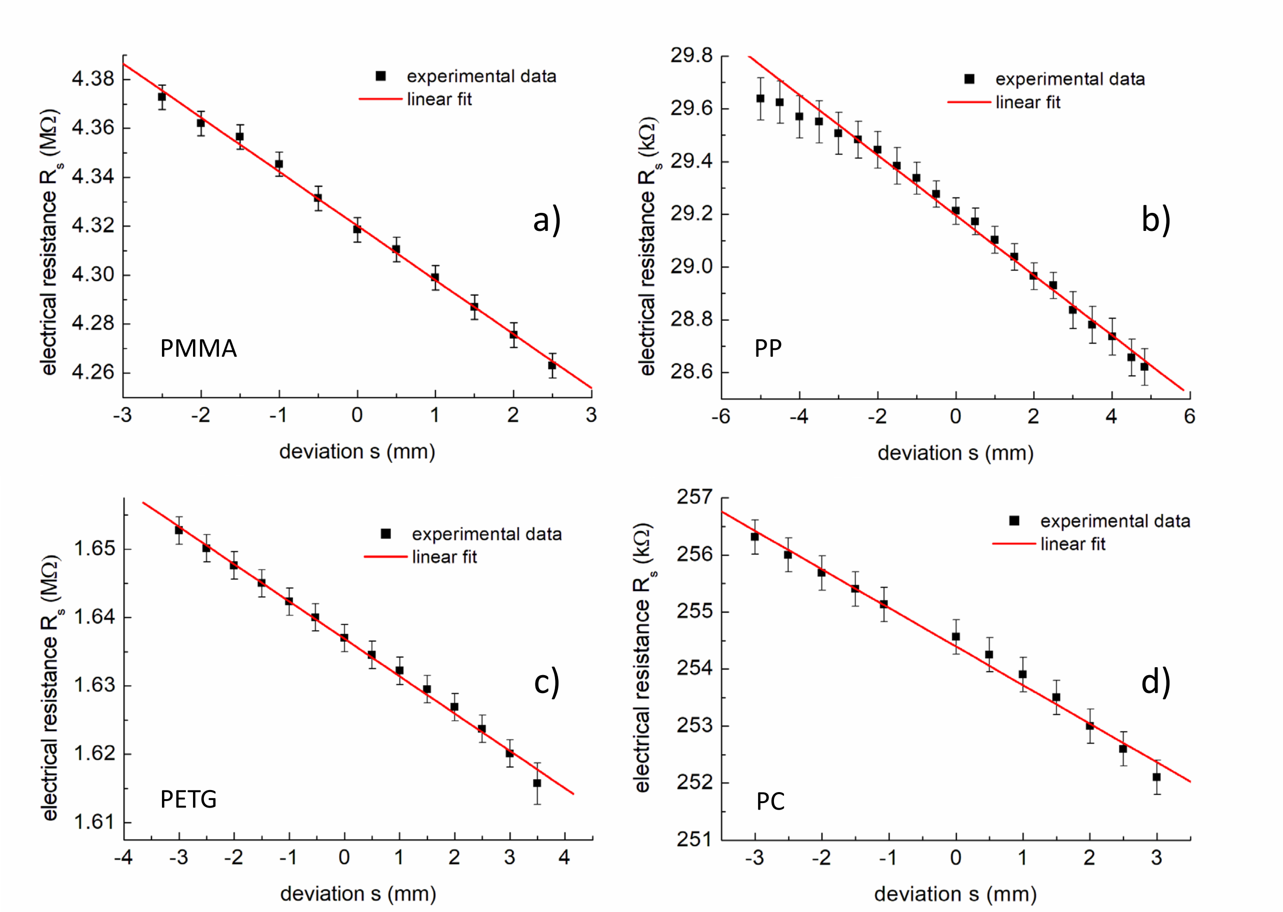

Fig.S2 - Electrical resistance as a function of the elastic deformation (bending) of the ion-implanted polymer slabs PMMA (a), PP (b), PETG (c) and PC (d). A linear behavior is observed for all samples in both, positive and negative bending deviations s.

An almost linear relationship between electrical resistivity and slab bending (deviation *s*) is observed for all samples considered here: PMMA (a), PP (b), PETG (c) and PC (d). A linear fit, red line, of the experimental data points is shown as a guide to the eye. For the PP polymer a slight deviation at the highest (negative) deviation values *s* is observed (see Fig.S2b).

Beam deflection, bending and Young modulus, length change and strain

As it is well known from elasticity theory, the equation of the deflection curve of a cantilever beam, fixed at one end and a concentrated load (or force) *F* acting on the free end, is given by [1]

$$s(x) = \frac{L_c^3 F}{6EI_y} \cdot \left[2 - 3\frac{x}{L_c} + \left(\frac{x}{L_c}\right)^3\right] \tag{S1}$$

where $I_y = (bh^3)/12$ is the axial momentum. Equation (S1) describes the beam deflection at any section in terms of x (Fig. S2). The maximum deflection at the end of the beam (x=0), *s*, is given by

$$s = \frac{4{L_c}^3}{bh^3} \cdot \frac{F}{E} \tag{S2}$$

where L_c is the effective length of the beam (polymer slab), i.e. the distance between fixing point at one end and the point where the force F is applied; b and h are the beam (slab) width and thickness, respectively. In our case, for all the samples, we have L_c=60mm, *b*=25mm and *h*=3mm.

E is the Young modulus and can be determined for all samples from the above equation eq.(S2) and using the data in Fig.S1. We obtain the following values: E_{PMMA}=2.7±0.1GPa, E_{PP}=1.20±0.15GPa, E_{PETG}=2.0±0.02GPa and E_{PC}=2.20±0.04GPa.

In order to determine the beam elongation (or contraction) due to the bending it is necessary to determine the radius of curvature of the deflected beam. Assuming for simplicity that the deflected slab (beam) curve can be approximated by a circle (this assumption is reasonable for small deflection values), the expression for the radius of curvature ρ is given by [2]

$$\rho = \frac{\left[1+\left(\frac{ds(x)}{dx}\right)^2\right]^{\frac{3}{2}}}{\left|\frac{d^2}{dx^2}s(x)\right|} \tag{S3}$$

Using the above relation eq.(S1) for *s(x)* at $x=L_c/2$, i.e. at the center of the deflected beam, we obtain the radius of curvature expression

$$\rho = \frac{bh^3 E}{6L_c F} \tag{S4}$$

The length change of the slab (beam), ΔL, due to bending is schematically shown in Fig.S3 and is given by

$$\frac{\Delta L}{L_c} = \frac{h}{2\rho} \tag{S5}$$

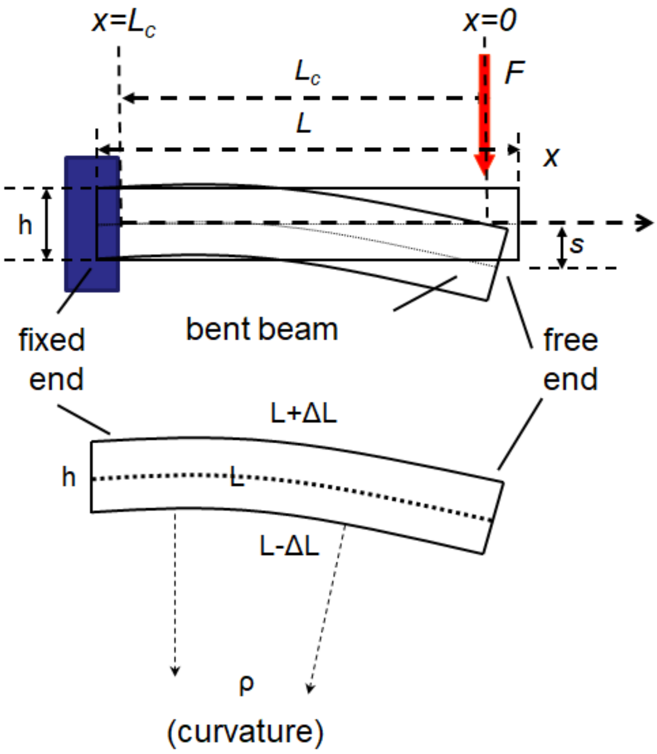

Fig.S3 Schematic representation of the slab (beam) bending and the geometrical parameters used for the curvature calculation.

The relative length change, $\Delta L/L_c$, can be defined as the strain along the x-axis ε (=ε_x). Using eq.(S4) we obtain for the relative length change of the polymer slab, i.e. the ion-implanted surface nanocomposite layer, the simple relation

$$\varepsilon = \frac{\Delta L}{L_c} = \frac{3L_cF}{\mathrm{b}h^2E} \quad \text{(S6)}$$

By using eq.(S2) we can express the strain ε as function of the beam deflection (deviation) s:

$$\varepsilon = \frac{\Delta L}{L_c} = \frac{3\mathrm{h}\cdot\mathrm{s}}{4\cdot L_c^2} \quad \text{(S7)}$$

These relations were used for the elaboration of graphs in Fig.6 and for the determination of the gauge factor *GF*.

References

[1] S.P. Timoshenko and J.N. Goodier, Theory of Elasticity, 3rd edition, McGraw-Hill International Editions (1970), 42-46.

[2] J.W. Harris and H. Stocker, Handbook of Mathematics and Computational Science, Springer-Verlag, New York (1998) 520-521.