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Distributed Light Sensing with Convex Potential Fibers

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Abstract: We report on a photoconductive fiber that supports decaying and convex electrical potential profiles capable of localizing a point of illumination, and propose a scheme to perform distributed optical sensing.

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Fibers present compelling opportunities for distributed sensing. The process of obtaining spatially resolved information is challenging and typically involves complex time domain measurements. Here we introduce an approach that enables distributed optical sensing in fibers without incurring the complexity associated with ultrafast detection schemes. We design and fabricate a fiber that supports, under particular boundary conditions, decaying and convex electrical potential profiles. This in turn allows us to localize a point of illumination with a spatial resolution that is close to 2 order of magnitude shorter than the fiber length, and to propose an approach to extract an arbitrary optical intensity distribution at a similar resolution.

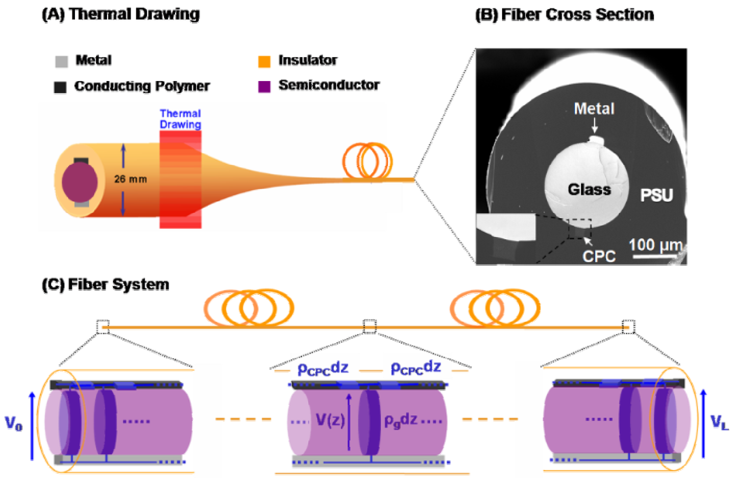

Fig. 1. **A**: Schematic of the thermal drawing process. **B**: Scanning Electron micrograph (SEM) of the cross section of the same fiber after thermal drawing. Close up on the interface between the glass core and the CPC electrode. **C**: Schematic of the fiber equivalent circuit.

Thermal drawing is used to produce tens of meters of fibers as represented on Figure 1 [1-3]. These contain a photoconducting glass core contacted by a metal conductor on one side and a composite channel on the other. The metal used is a Tin-Lead eutectic composition while the composite comprises a carbon black filled Polycarbonate (CPC). The axial invariance of the fiber appears at first to preclude the derivation of axially dependent information.

To break this symmetry an electrical bias is applied to the fiber as shown in Figure 1C. The differential equation that governs the change of potential $V(z)$ along the fiber length in the steady state is given by:

$$\frac{\partial^2 V}{\partial z^2} = \frac{V(z)}{\delta(z)^2}, \text{ with } \delta(z) = \sqrt{\frac{\rho_g(z)}{\rho_{cpc}} \frac{\pi}{2} S_{cpc}} \tag{1}$$

where ρ_g and ρ_{CPC} are the glass and CPC resistivities respectively, and S_{CPC} is the cross section surface of the CPC electrode. The solution of this equation for an homogeneous system (δ independent of z) of length L, where the bias is applied at one fiber end only ($V_0 = 100\ V$ and $\partial V_L/\partial z = 0$ (no accumulation of charges)) is given by:

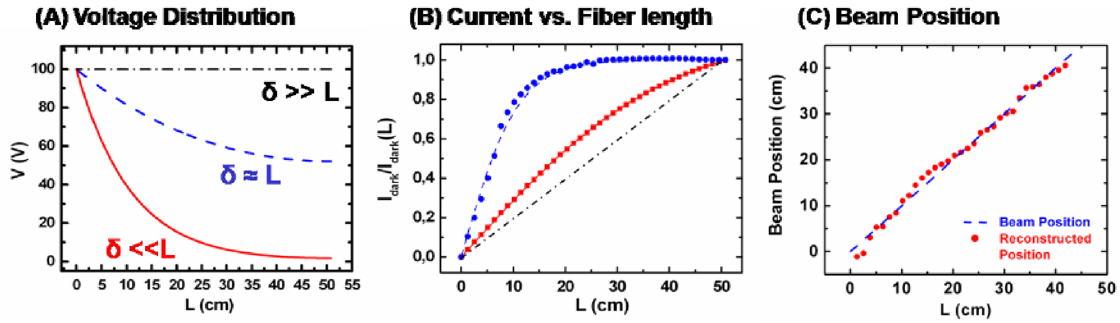

Fig. 2. A: Theoretical curves of the voltage distribution along a fiber axis for different values of *δ*. B: Normalized dark current vs. fiber length. The curves are the theoretical values derive from the calculated voltage distribution while the dots are experimental results. C: Reconstruction of a beam position along the fiber lenght. Curve shows real experimental position while the dots are the reconstructed values.

$V(z) = V_0 \cosh((L-z)/\delta)/\cosh(L/\delta)$ and is shown on Figure 2A for different decay lengths *δ*. This approach was tested experimentally by measuring the dark current versus fiber length (given by $I_{dark}/I_{dark}(L) = tanh(L/\delta)$) as shown on Figure 2B for the same *δ* values of Figure 2A. The agreement between theory and experiment is excellent.

The use of equipotential metallic electrodes (for which $\delta >> L$) has precluded us from breaking the fiber axial symmetry [1-3]. As *δ* gets smaller however, the voltage $V(z_0)$ at a location z_o varies depending on which side of the fiber is biased. The free charges generated by a point of illumination at z_o in the semiconducting glass will experience a different potential. Two photo-currents can hence be recorded, and their ratio associated to a unique position of the beam along the fiber axis (as long as the beam size is much smaller than the fiber length). The beam localization can therefore be reconstructed as shown on Figure 2C where sub-centimeter resolution was obtained over a half meter long fiber.

If now we apply a bias at both fiber ends as depicted on Figure 3A, the potential is given by (still for a *δ* independent of *z*): $V(z) = [V_L \sinh(z/\delta) + V_0 \sinh((L-z)/\delta)]/\sinh(L/\delta)$ as shown on Figure 3B, which is a convex function of *z*. This model is verified experimentally on Figure 3C. This approach enables to vary V_0 and V_L to obtain a large set of photo-currents from which more complex optical signals can be reconstructed. We will show however that in this scheme, the photo-currents aren't independent and only provide limited information on the optical intensity to be reconstructed. We will then present an alternative strategy that uses two photconducting glasses with different decay lengths. The convex potential distribution can be imposed by the glass of shorter *δ* and known at all time. The set of photocurrents recorded in the longer *δ* material together with the voltage profiles, form a Fredholm differential equation that can be used to extract the unknown optical field intensity along the fiber axis, with resolution of potentially 2 to 3 orders of magnitude smaller than the fiber length. This approach can have significant impact in applications such as large area optical and thermal sensing systems for industrial control and medical imaging, remote sensing and smart fabrics.

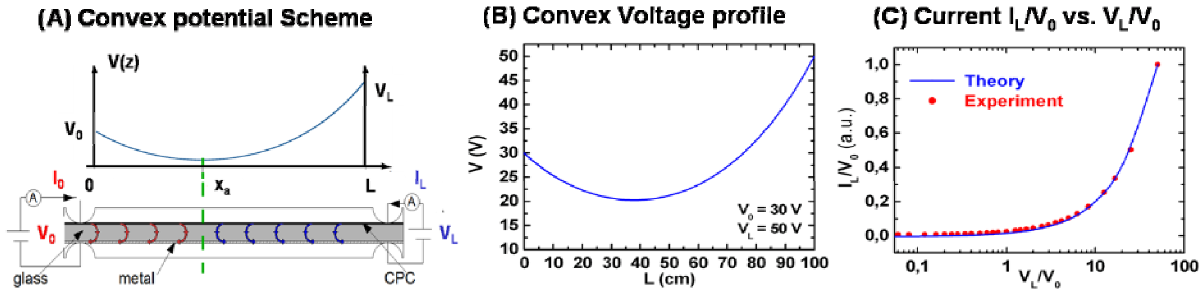

Fig. 3. A: Schematic of the convex potential scheme. At the potential minimum the current separates to reach one fiber end or the other B: Computed convex voltage profile along the fiber axis for $V_0 = 30$ *V and* $V_L = 50$ *V*. C: Current exiting one end of the fiber I_L/V_0 vs. V_L/V_0,

[1] M. Bayindir, F. Sorin, *et al.*, "Metal-insulator-semiconductor optoelectronic fibers", Nature **431**, 826- 829 (2004).

[2] F. Sorin, *et al*., "Multimaterial Photodetecting fibers: a geometric and structural study", Advanced Materials **19**, 3872–3877 (2007).

[3] F. Sorin, *et al*, "Exploiting the collective effects of optoelectronic devices integrated in a single fiber" NanoLetters , **9** (7), 2630–2635 (2009).