Bridge percolation: electrical connectivity of discontinued conducting slabs by metallic nanowires

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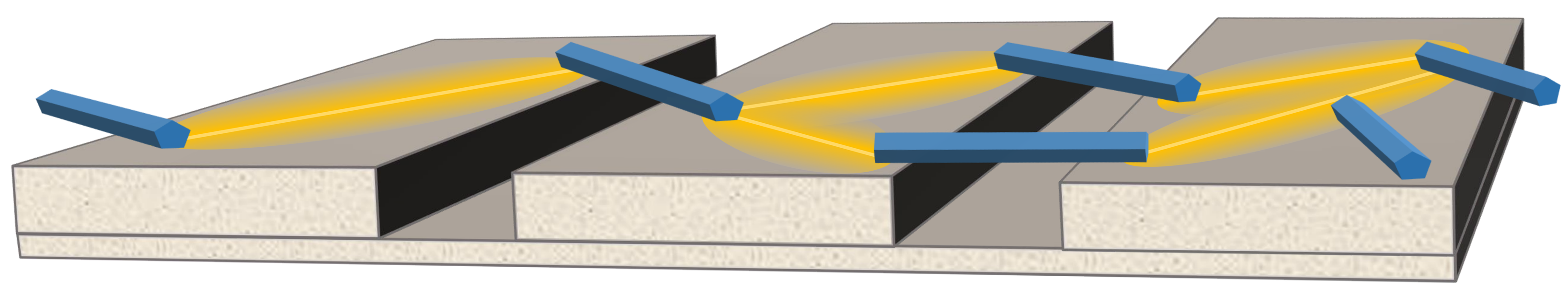
Introduction

In this work, we introduce a novel type of local percolation phenomenon, that we propose to nickname **bridge percolation**, used to investigate the conduction properties of a **new hybrid material** that combines **sparse metallic nanowire networks** and **fractured conducting thin films** on flexible substrates. This work introduces an original concept leading to the design of a novel composite transparent conducting material potentially useful for a wide range of electronic and optoelectronic device applications.



Methods

Analytical developments

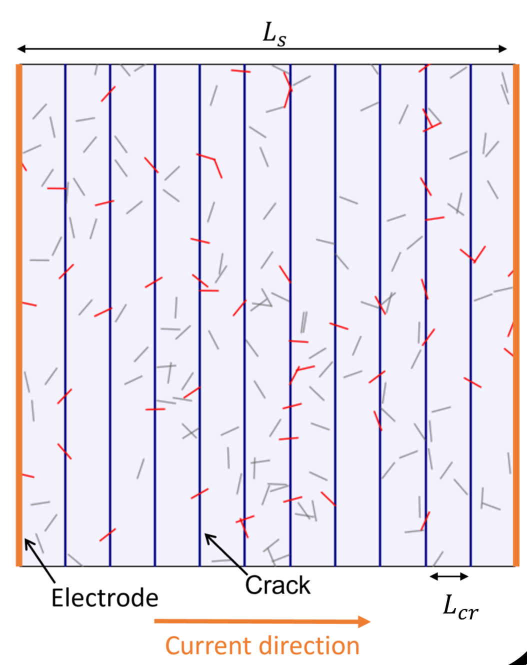
The probability that current injected orthogonally to the cracks direction reaches the other side of the film constitutes an **electrical percolation** problem. For the system to reach percolation, all the cracks must be **bridged** by at least one NW [1].

Percolation probability ∝

- *NWs normalized interaction length:* L_{NW}/L_s
- *Total number of cracks:* $N_{cr} = L_s/L_{cr}$

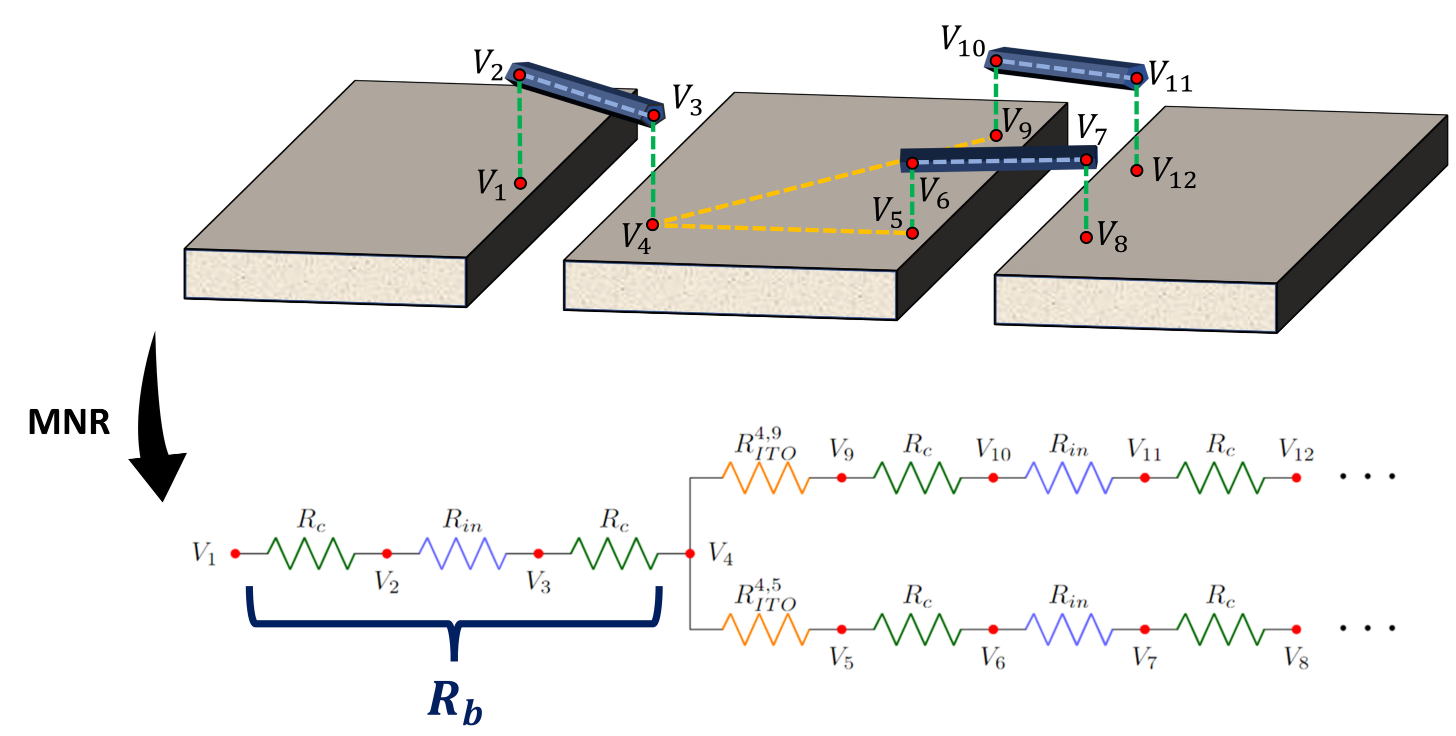
$$amd_c \propto \frac{L_s}{L_{NW}} \ln(1 - 2^{1/N_{cr}})$$

Bridge percolation



Conductivity modeling

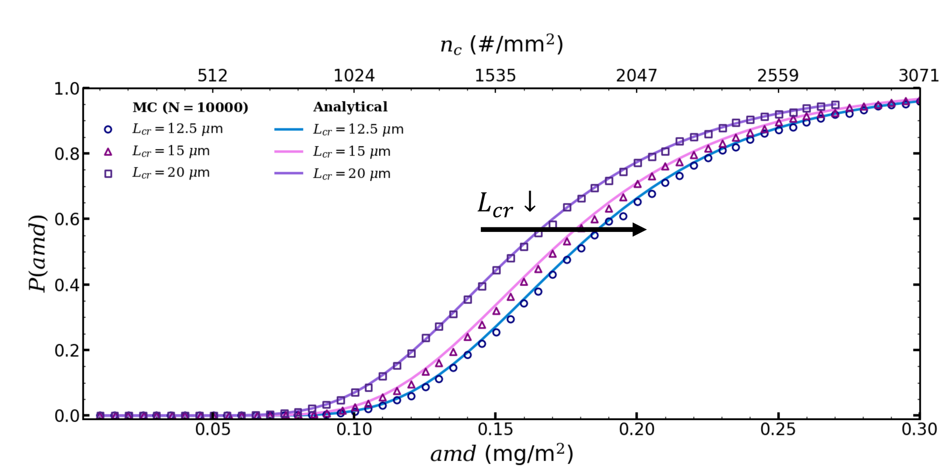
Using the Multi-Nodal Representation (**MNR**) method [2], well-defined voltage nodes and resistive elements in the system are identified. The system is then solved using the Modified Nodal Analysis [3] and the equivalent resistance is explicitely determined.



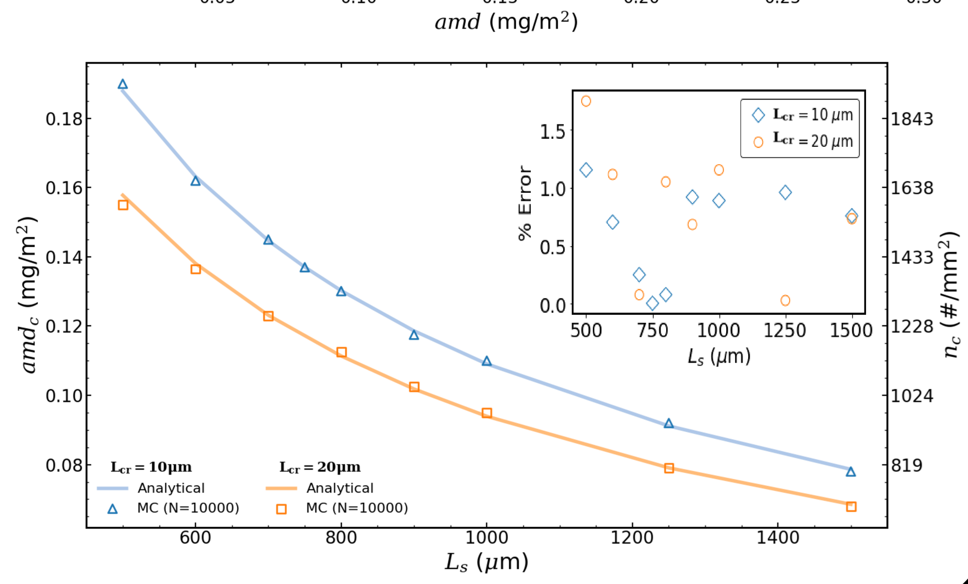
Results

Percolation threshold evolution

- **Logistic** function evolution typical of **percolating** systems



- **Explicit scaling** with L_s, unlike conventional percolation theory.
- **Significantly lower** critical areal mass density (amd_c) than those associated to conventional percolation [4].

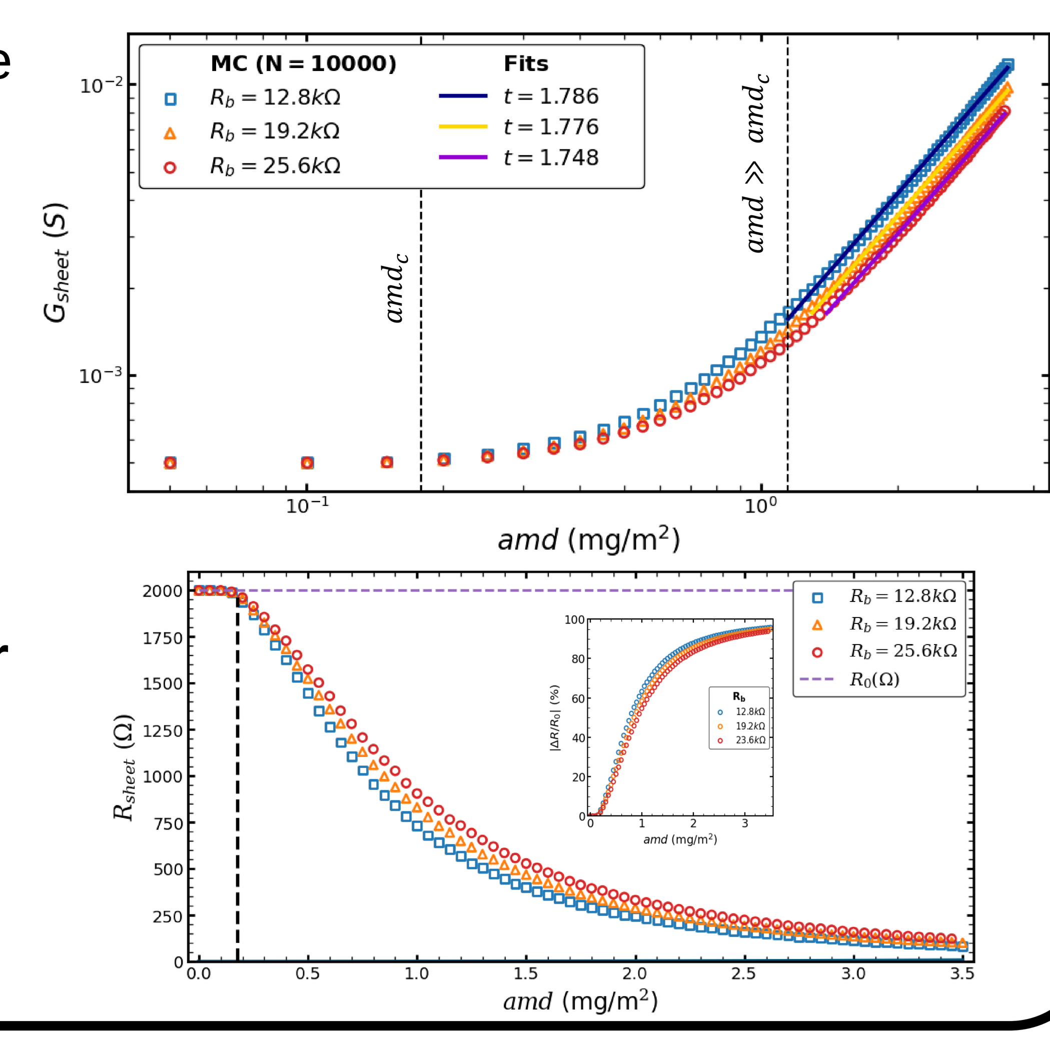


Conductivity scaling

- **Power law** dependance for high densities:

$$\sigma \approx (amd - amd_c)^{1.77}$$

- **Low impact** of the **contact** resistance R_c
- **90%** conductivity **improvement** with $amd = 3.5$ mg/m².
- **Asymptotic behavior** associated to the equivalent bridge resistances.



Take-home message

1. **Sparse, low-density MNW networks can be used in combination with a discontinuous film to form an original hybrid TCM.**
2. **We introduce the novel concept of bridge percolation.**
3. **Fractured ITO films can be efficiently cured using bridge percolation.**

References

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Acknowledgments

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Contact information