Printed Neutron Converter Foils

Can conventionally printed neutron converters substitute costly coating processes?

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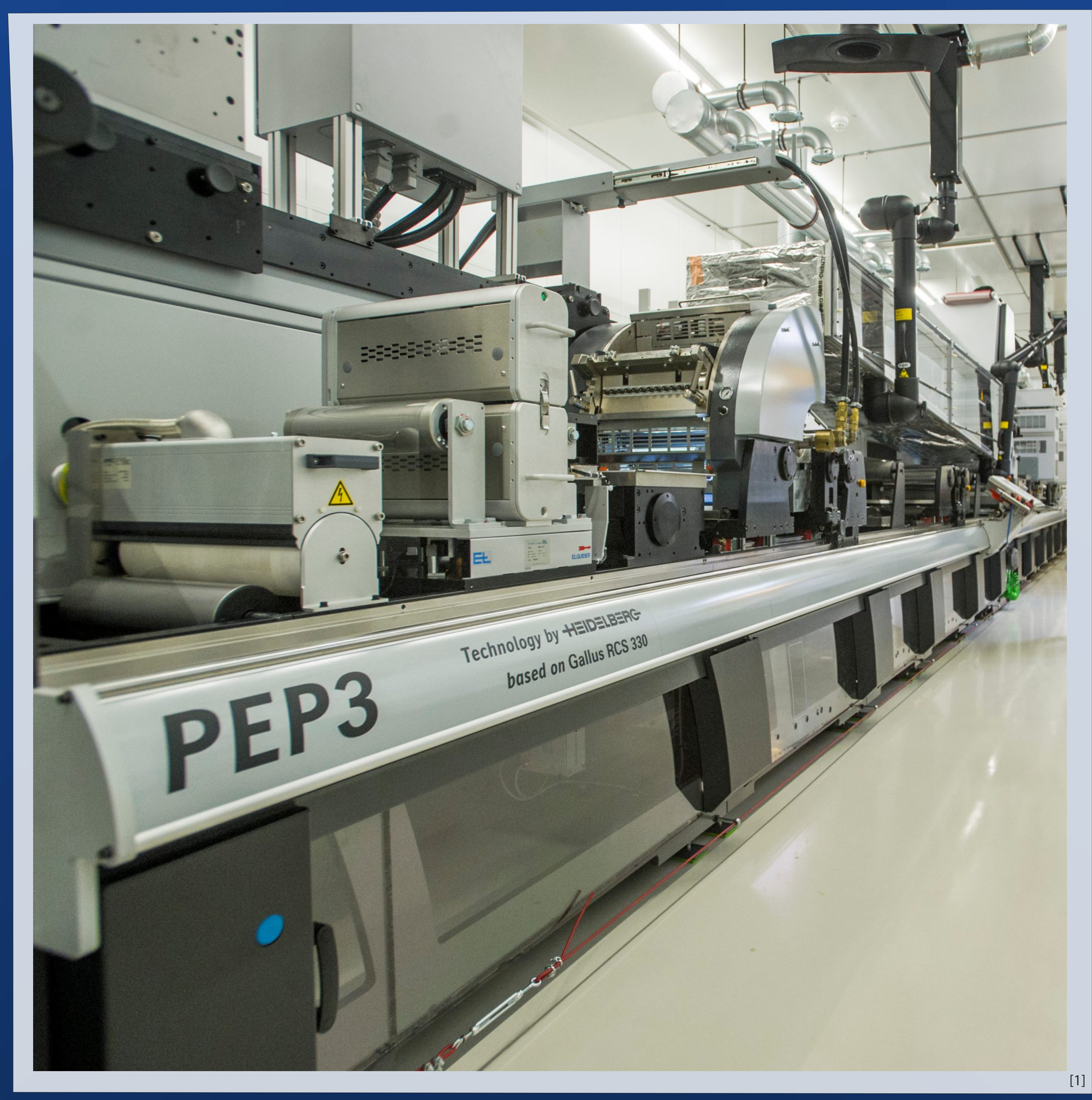
The cost increase of helium-3 has sparked the development of alternative detection technologies, specifically the use of boron carbide (B_4C) converters is one of the pillars of next-generation neutron detectors. While producing high-quality films, sputter-deposition is limited in the deposition area, and requires costly and energy-intensive vacuum processing. Lithium fluoride (LiF) can reach a similar performance to 1.5 µm B_4C at around 20 µm layer thickness. While its lower melting point and lower costs are advantageous, there are currently no ideal film deposition techniques for this material. Therefore, the investigation of new approaches for the fabrication of neutron converter foils are necessary to improve fabrication costs, deposition over large areas and explore a larger palette of materials. The field of Functional Printing offers several advantages to face these challenges. It provides the cost-efficient, high throughput and large area fabrication inherent to printing techniques and enables the resource efficient deposition of functional materials. Furthermore, all processes are compatible with mechanically flexible substrates, which allows the converters to be inserted into different types of detectors. In our recent project, we investigate the deposition of B_4C and LiF materials via screen printing and bar coating to fabricate high performance neutron sensing flexible films. The aim is to investigate the correlation between printing process, film properties and neutron detection efficiency and to establish the material-process-functionality relations necessary to optimize the detector performance, specifically in terms of outgassing. First small-scale samples show encouraging results in terms of performance and mechanical stability. Thanks to the industrial readiness of printing technology we expect a potential pathway towards developing a new generation of printed neutron converter foils to support the development of state-of-the-art large-area instruments.



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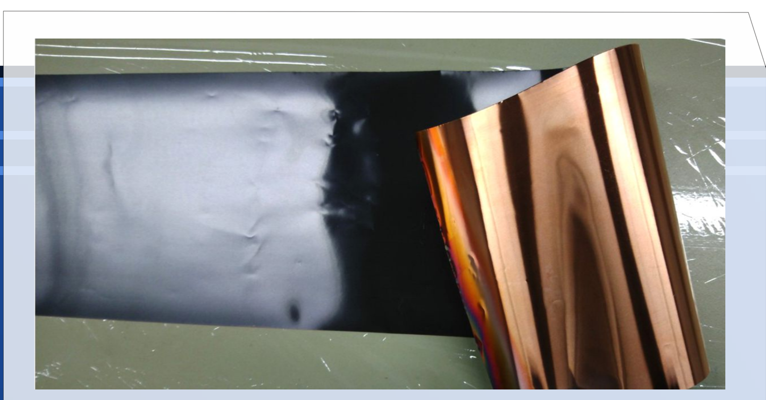

Cost estimation

Type*	Costs**	Abs. Eff.***
^{3}He	2500 €	60 %
$^{10}BF_3$	1500 €	20 %
$^{10}B_4C$ conv	1000 €	12 %
^{6}LiF printed	700 €	12 %
$^{10}B_4C$ printed	400 €	11 %

*Proportional counter tubes examples of different sizes to match similar instrument performances. Commercial tubes He: 2″ x 12″, BF_3: 2″ x 30″. Conventional sputter-coated B_4C tube 2.3″ x 47″.

**Costs for a proportional counter, for He mainly the gas filling, for BF_3 (hazardous) 1000 € for the tube, others 300 €.

***thermal neutron absorption efficiency.

Applications

- **segmented** detectors
- **large-area** detectors
- instruments with **high-ToF resolution**
- **table-top** detectors
- **radiation** monitoring
- non-proliferation technologies
- **environmental** monitoring
- absorption coatings
- **cost-efficient** solutions with unconstrained conversion layer demands


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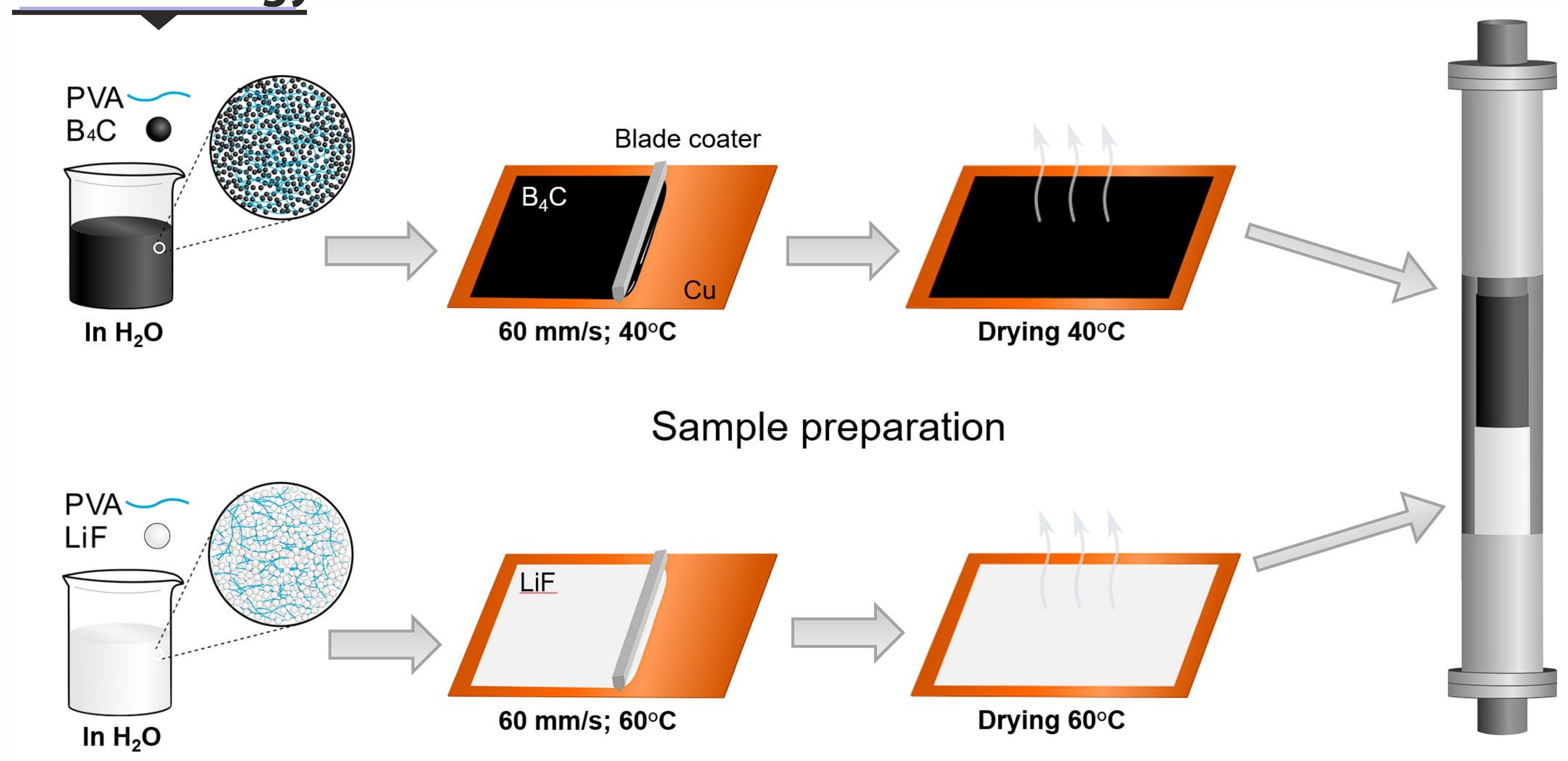
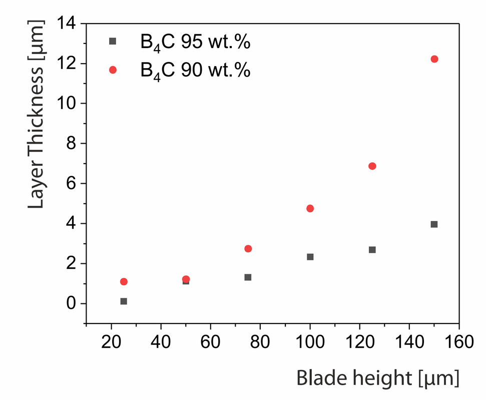
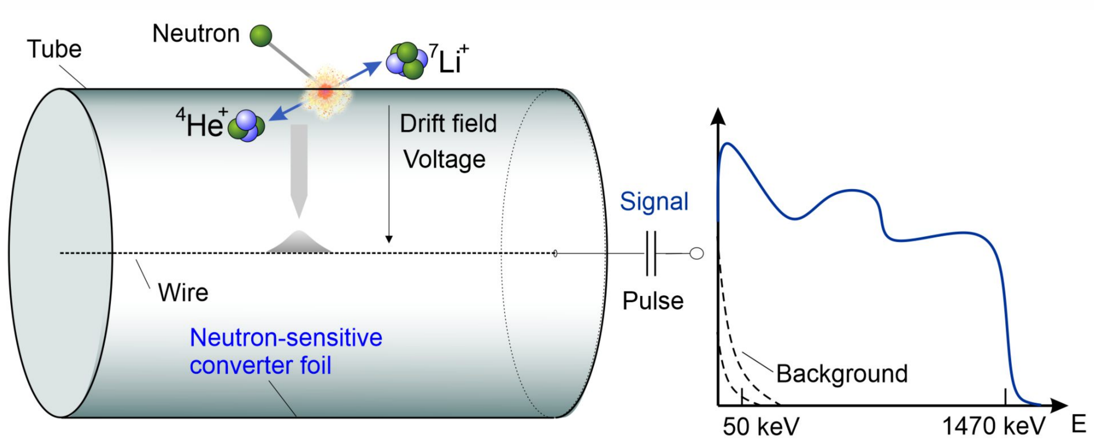
Methodology

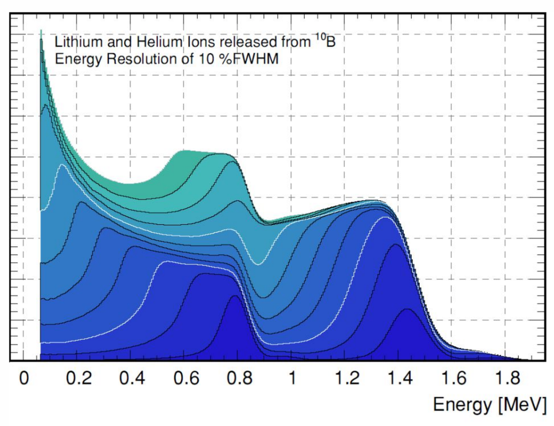




Flexible converter foils



Schematic of a boron-based proportional counter tube

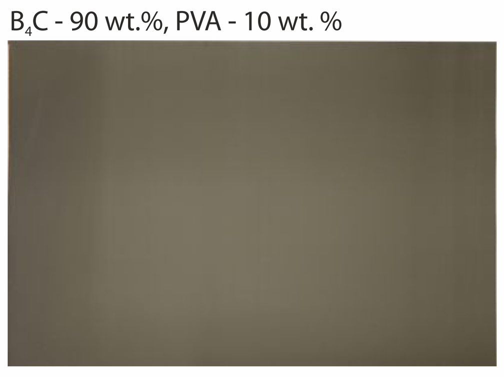


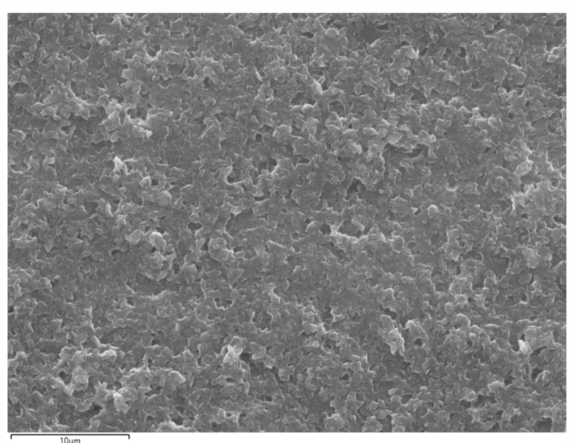
Simulation of conversion ion spectra with increasing layer thickness

Results

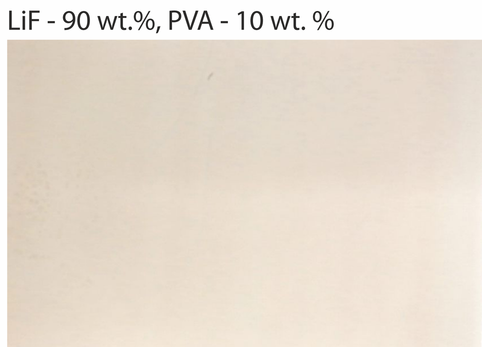
Morphology

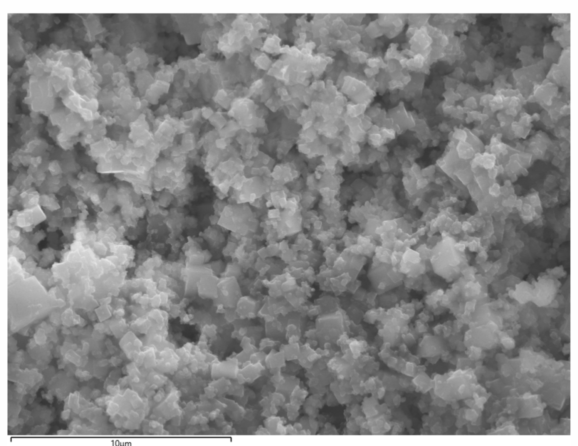
B_4C - 90 wt.%, PVA - 10 wt. %





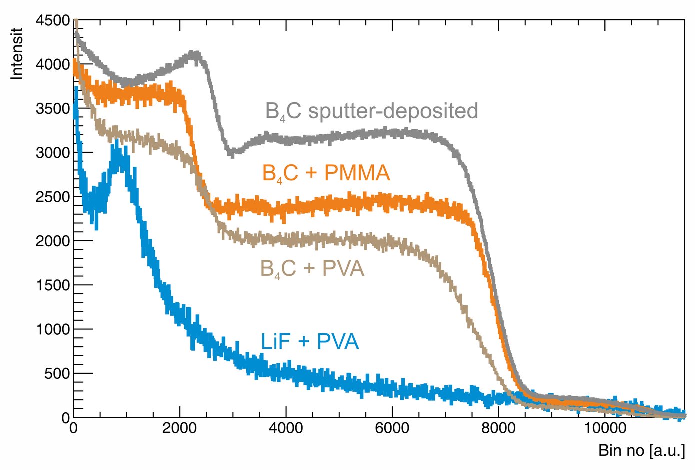
LiF - 90 wt.%, PVA - 10 wt. %





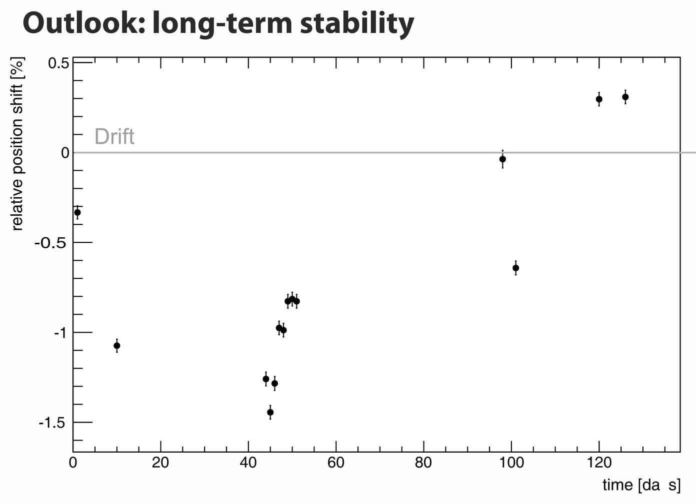
Optical and SEM* of B_4C and LiF based films on Cu substrates
*Wen-Shan Zhang, Heidelberg University

Conversion ion spectra



Measured spectra with converter foils mounted in proportional counter tubes (d = 54 mm, Ar:CO2 90:10, 300 mbar). The gain is not uniform. The sharpness of the edges is a measure of layer thickness variation. Thickness of boron layers: PMMA: 2.2 µm, PVA: 3 µm, sputtered 1.5 µm. Lithium + PVA: 30 µm.

Outlook: long-term stability



Outgassing is a concern for the long-term stability.

Any organic material can degrade the performance of a counter tube easily. Baking is therefore required for removing residual water and volatile substances. First tests indicate a good stability. Here: position-shift of the spectrum.

Influence of the binder

	Thickness [µm]	He ion detection [%]	Li ion detection [%]
B_4C	1.5	39.7	29.0
B_4C + 10% PVA	1.5	40.3	29.7
B_4C + 10% PMMA	1.5	39.5	29.8
B_4C + 10% PVA 0.5% W	1.5	40.4	30.0

Lithium fluoride vs. boron carbide simulated efficiencies (TRIM)

	Thickness [µm]	Ions reaching the gas total / cut 100 keV / [%]	Layer efficiency total / cut 100 keV [%]
^{6}LiF	10.0	58.1 / 55.9	3.3 / 3.2
	15.0	48.9 / 47.1	4.2 / 4.1
	17.5	45.7 / 44.1	
	18.5	44.6 / 43.0	
	20.0	43.4 / 41.8	4.9 / 4.8
	22.5	40.4 / 38.8	
	30.0	33.3 / 31.9	5.7 / 5.5
$^{10}B_4C$	0.8	84.0 / 77.0	
		81.0 / 74.0	
	1.0	79.0 / 71.0	
	1.1	77.0 / 69.0	
	1.3	73.0 / 63.5	
	1.5	69.0 / 59.0	
	1.7	64.0 / 54.7	
	1.9	60.0 / 51.0	
	2.1	56.0 / 48.0	

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