Laser-assisted direct-writing of thermoelectric generators

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Outline

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1. Motivation
2. Laser-induced forward transfer
3. Thermoelectric generator designs
4. Results
5. Comparison with existing generators
6. Conclusion

1.Motivation (I)

Thermoelectric generation (TEG) via **Seebeck effect**

Current thermoelectric (TE) research:

•Increasing efficiency of **materials** (lowering thermal conductivity & electrical resistivity, increasing Seebeck coefficient).

• New, inexpensive and non-toxic materials

• **Devices** with increased power density (via scaling, packaging) + novel manufacturing methods

1.Motivation (II)

- **Reduce complexity** in manufacturing (using a laser-assisted transfer technique):
  - Sequential transfer
  - Fast deposition (Single laser pulse process)
- **Combine complex materials in device**
  - Intact transfer of solid material onto polymer
  - Preserving phase of material

➡ **Objective: Fabricate and test working thermoelectric generator via laser-induced forward transfer**

2.Laser-induced forward transfer

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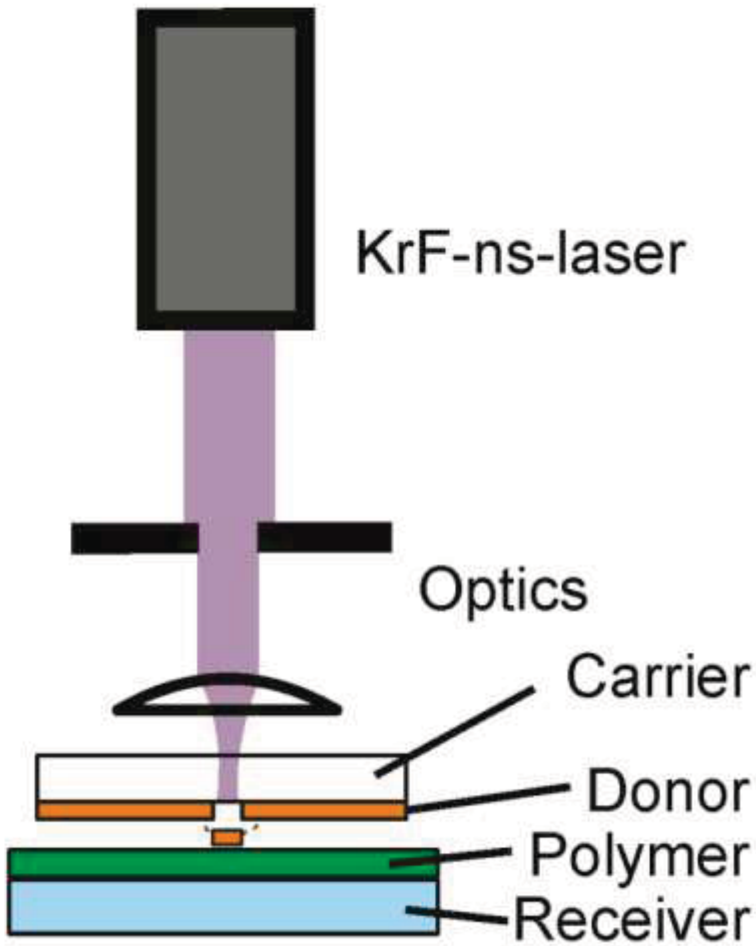
- Laser-induced forward transfer (LIFT)
- **Additive direct-write**
- **Thin film** technique for the fabrication of electronic devices
- Transfer **solid** materials in **intact** state
- Preserve physical properties of donor



2.Laser-induced forward transfer

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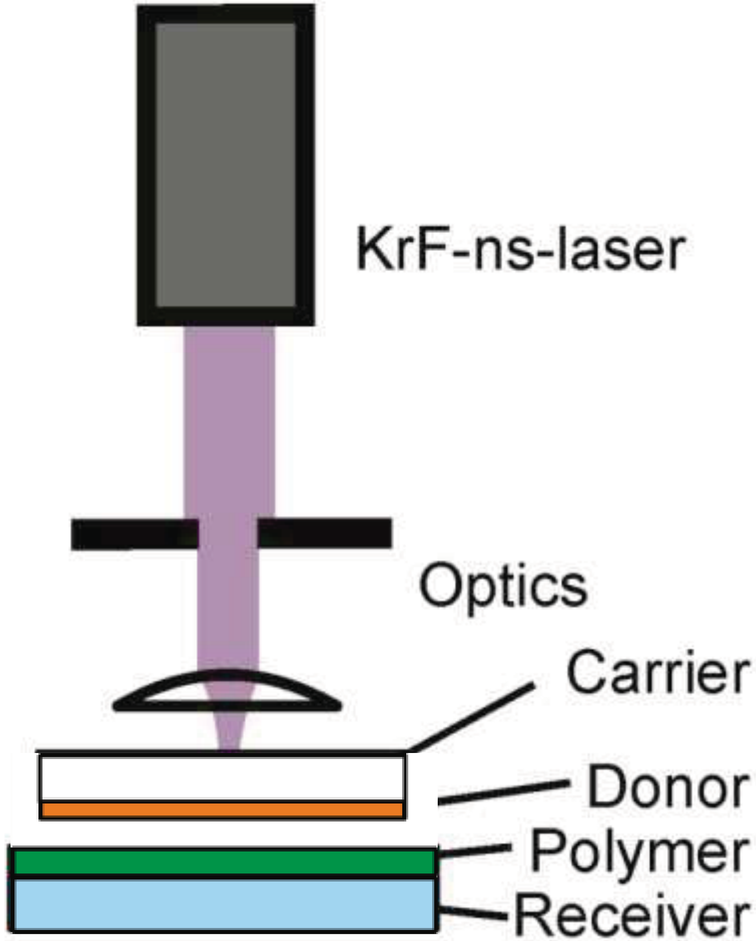
Experimental:

- UV excimer laser system, 248nm
- 20ns pulses, max. 0.4J pulse energy, 3x demagnification
- Typical donor/receiver spacing of some microns or in contact.



2.Principle of LIFT

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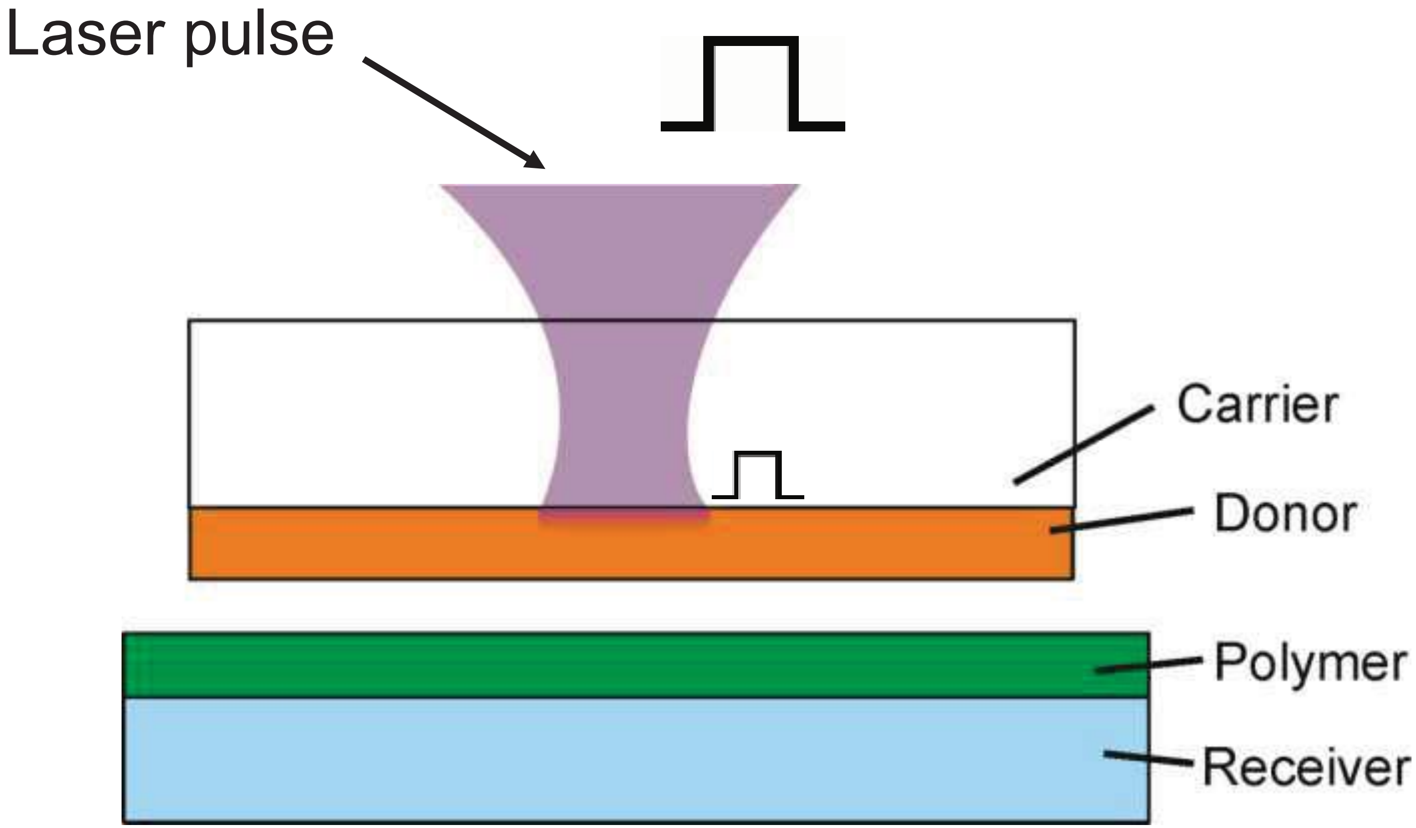
1) Absorption



2.Principle of LIFT

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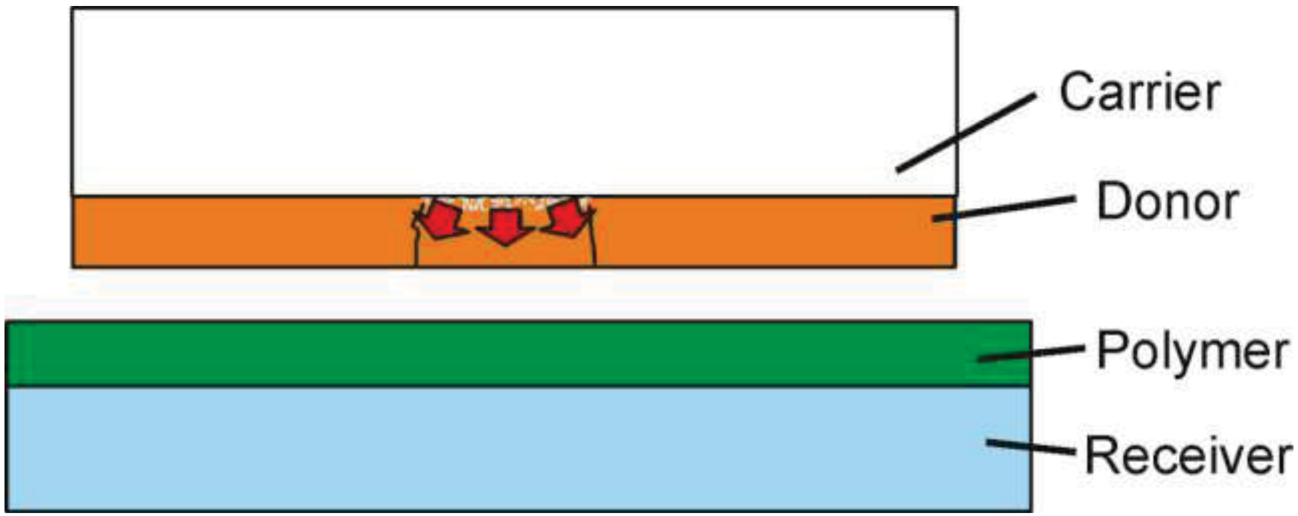
2) Pressure build-up



2.Principle of LIFT

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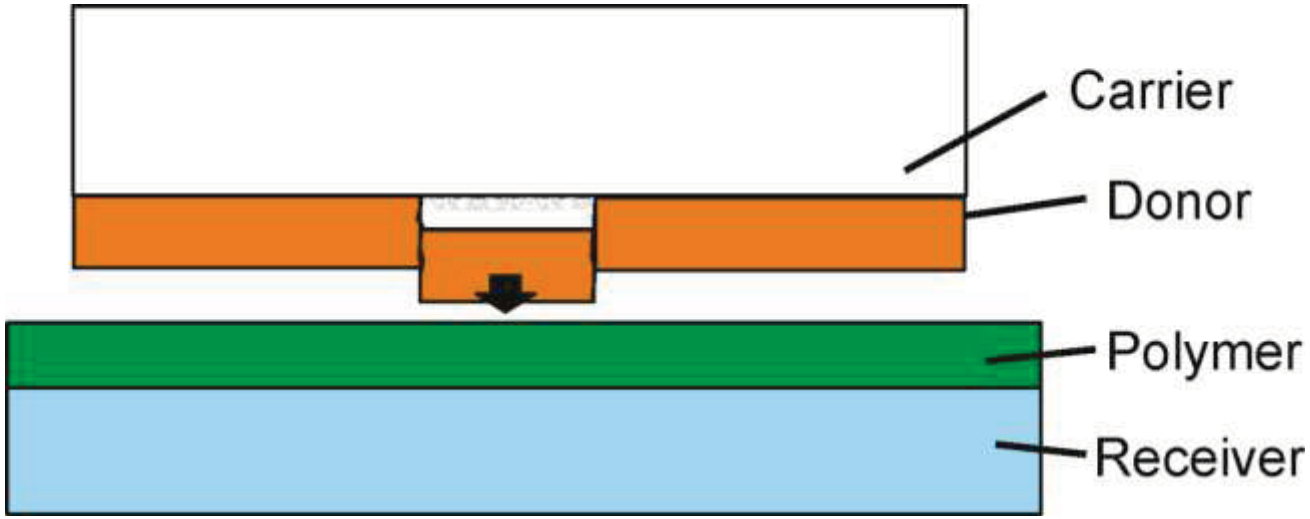
3) Transfer



2.Sequential transfer

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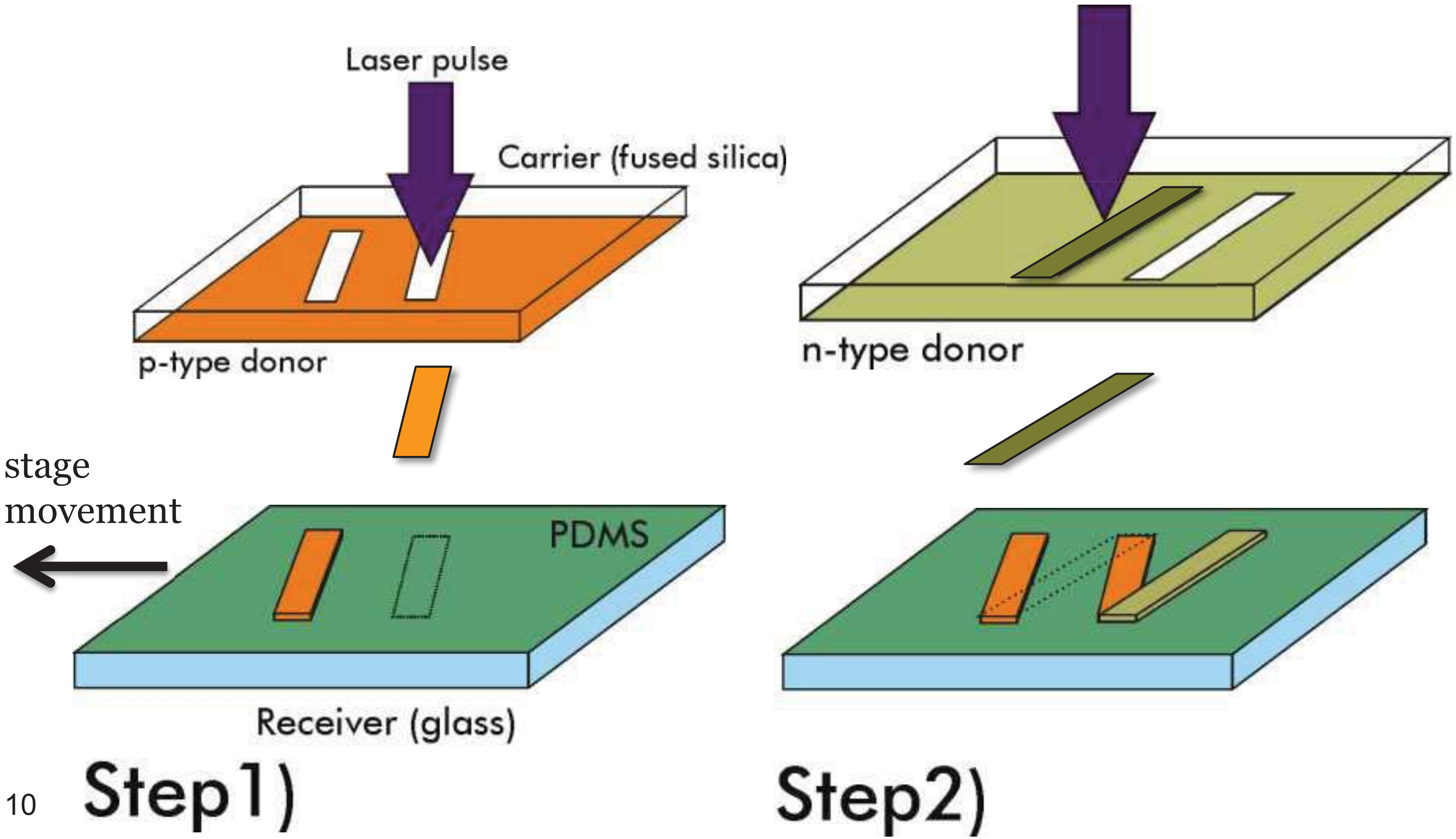

3.Designs of TEG

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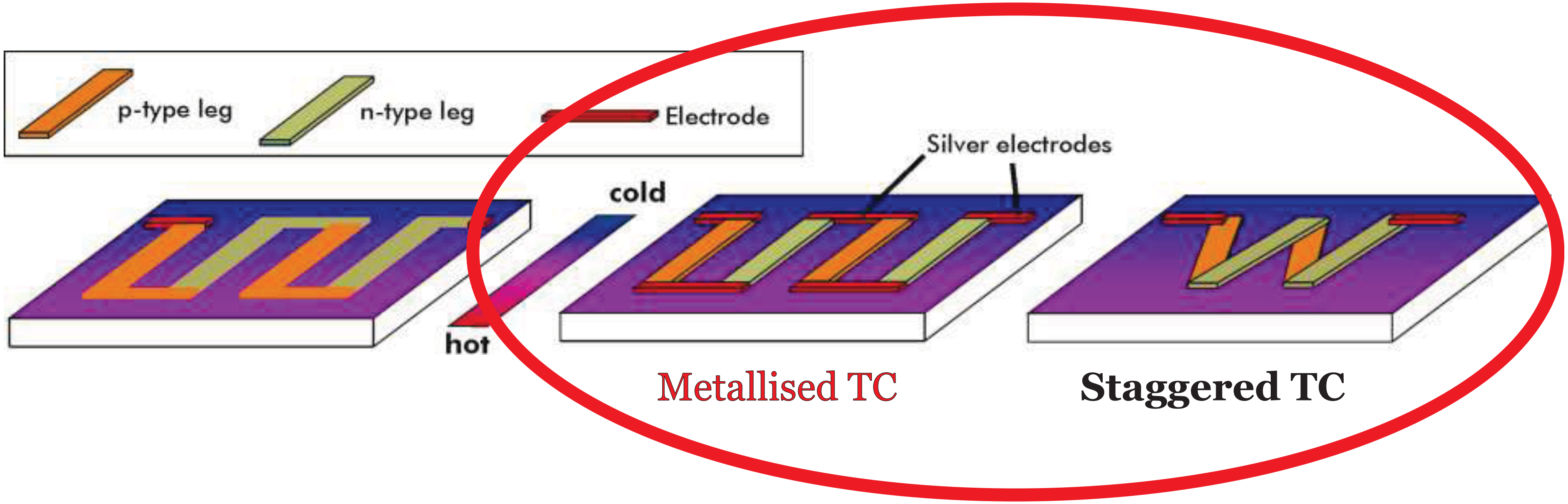
- Lateral-lateral design: heat and current flow in substrate plane
- Design chosen as most common thermoelectric thin film device technology
- Two designs: **Silver (Ag)-contacted** & **staggered thermocouples (TC)**



4.Results- Morphology

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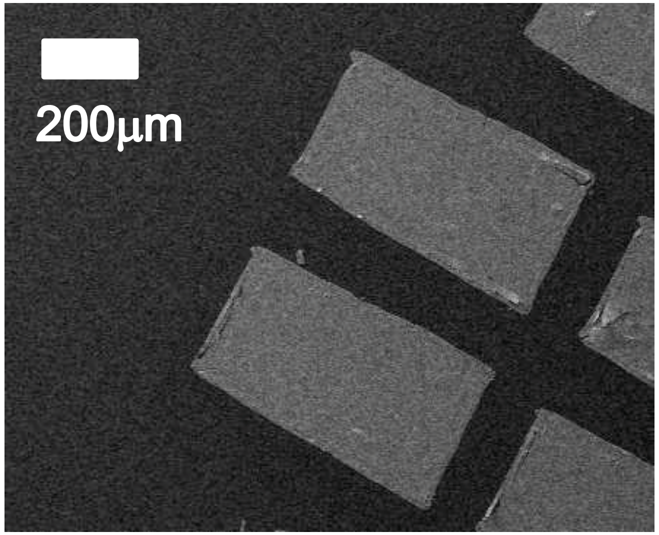
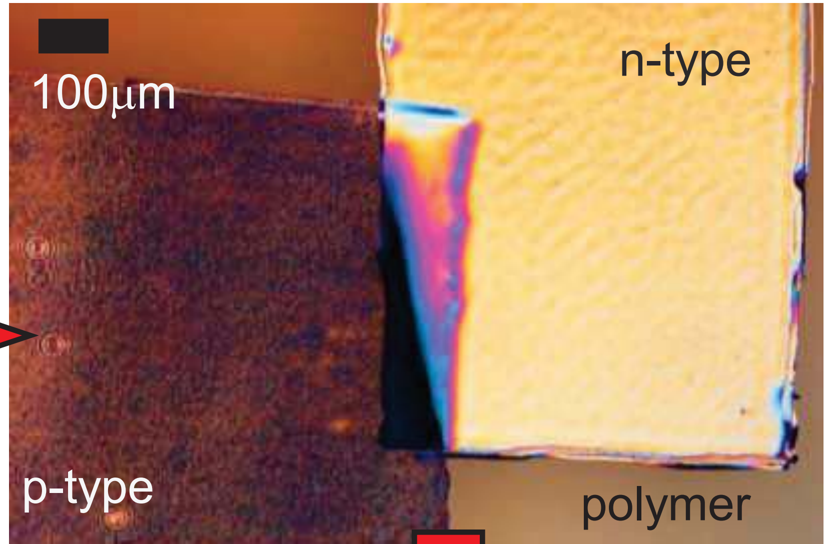
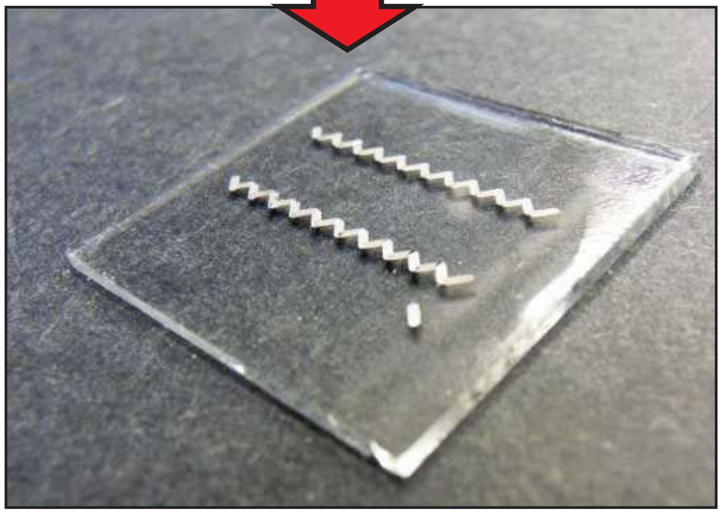


Feinaeugle et al., Appl Phys A (2012)

This work





Substrate size: ~25mm x 20mm

Deposition of chalcogenides (Bi_2Se_3, Bi_2Te_3 and $Bi_{0.5}Sb_{1.5}Te_3$) via LIFT without intermediate release layer onto polydimethylsiloxane (PDMS)-coated glass substrate:

- Preservation of >75% of Seebeck coefficient
- Deposited areas up to 15mm² area

4.Electrical characterisation

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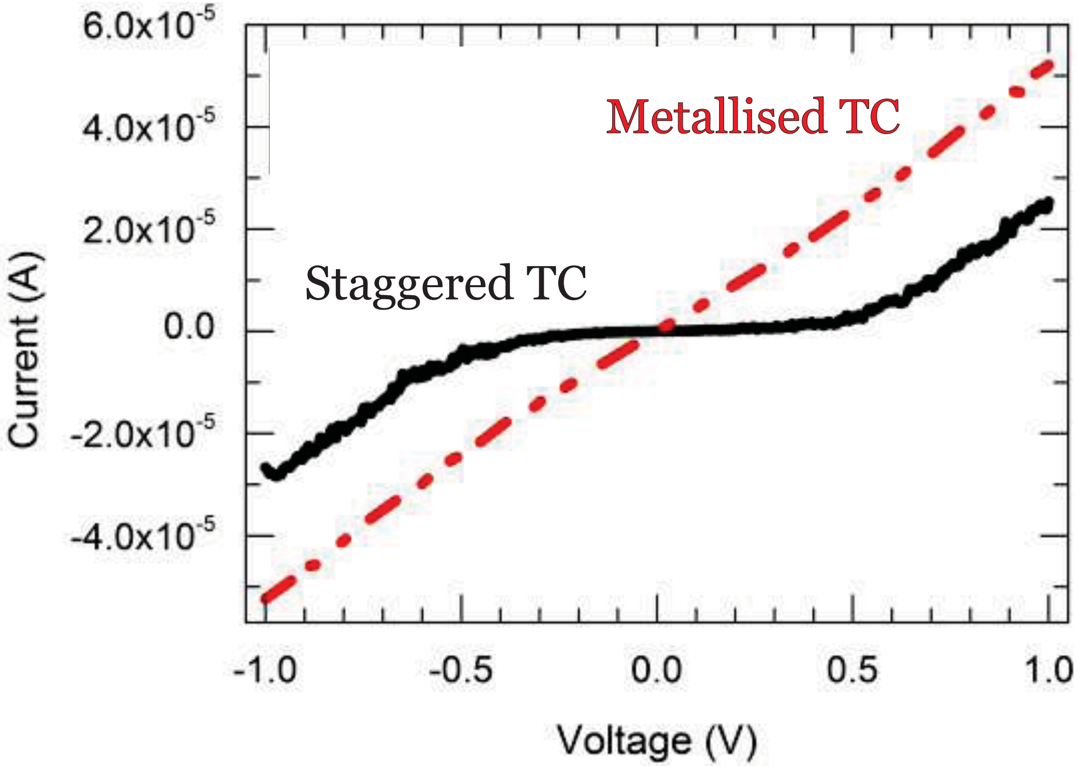

For single TC:

- Contact resistance (staggered TC) ~2kΩ
- Total resistance: 9kΩ
- Large TE element resistance due to non-optimised materials

Material	Resistivity [Ωm] (±10%)	Seebeck coefficient (donor) [μVK-1] (±5%)	Seebeck coefficient (deposit) [μVK-1] (±5%)
Bi_2Se_3	0.04	-121	-93
Bi_2Te_3	0.003	-64	-49
$Bi_{0.5}Sb_{1.5}Te_3$	0.0006	+177	+142

4.Thermoelectric measurements

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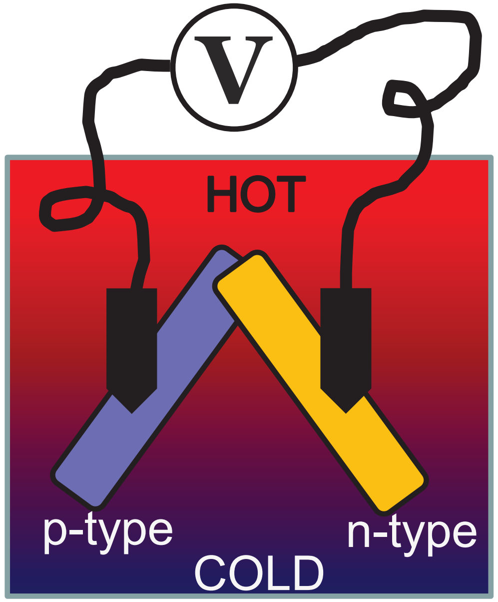

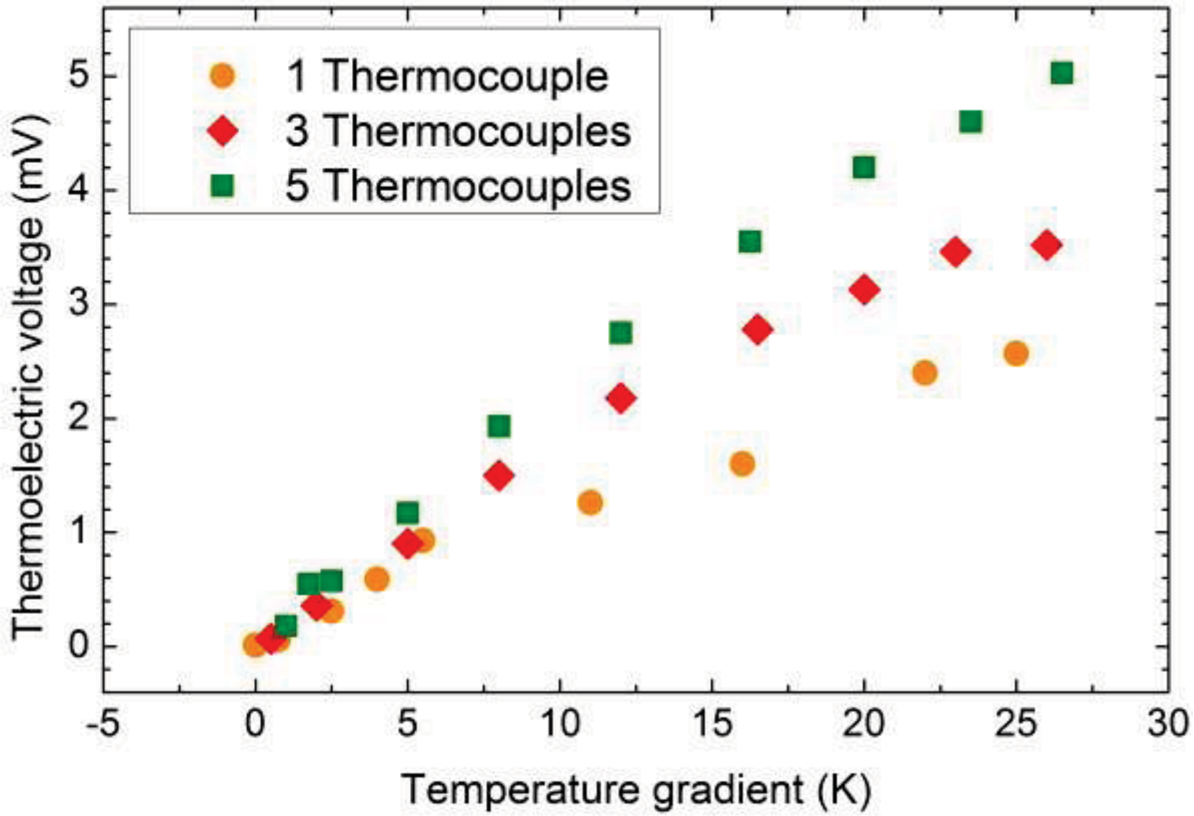

- Resulting max. Seebeck coefficient for a TC **~170μV/K (staggered design)**
- Max. output voltage **~10mV** (not shown)

4. Metallisation

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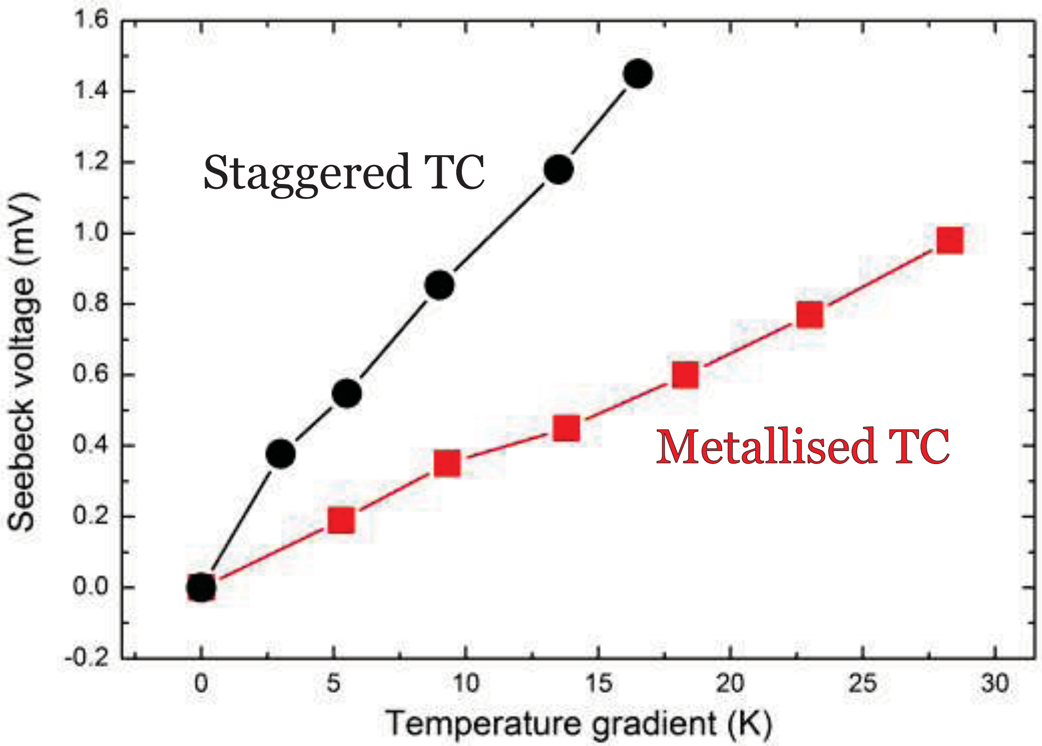
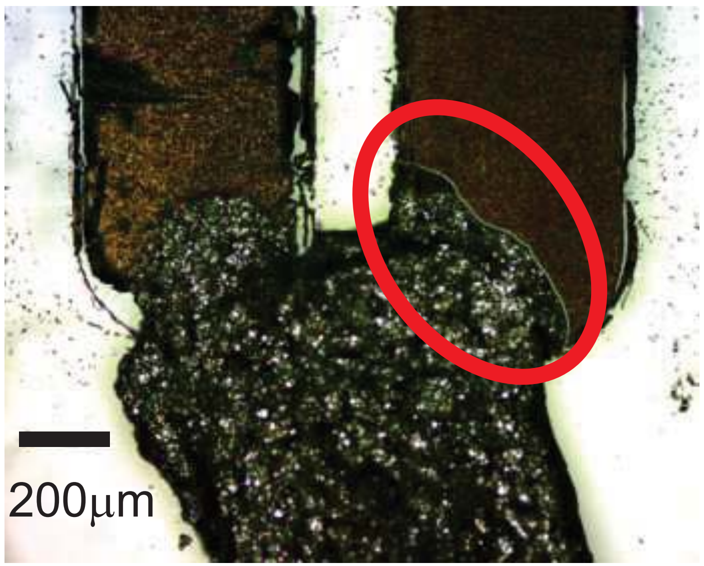
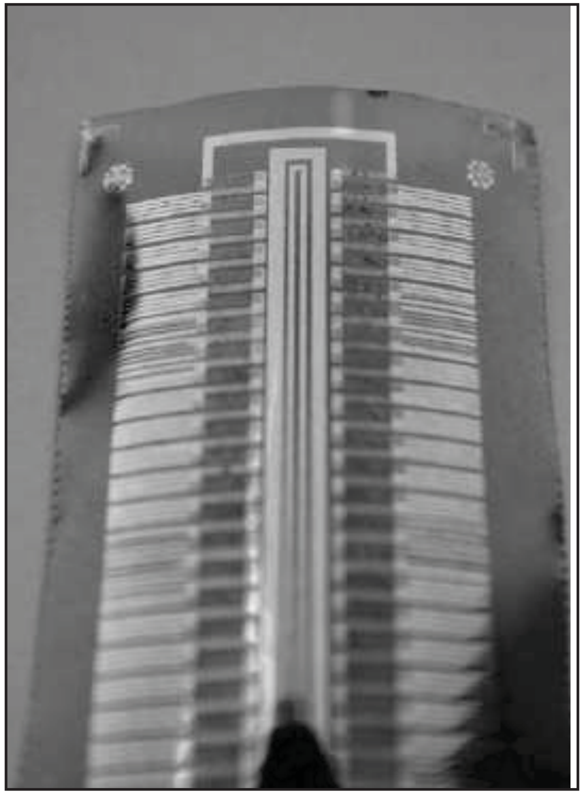
- Improves junction contact, but increases reverse diode current + reduces Seebeck voltage!
- In some cases: cracking of TE elements!



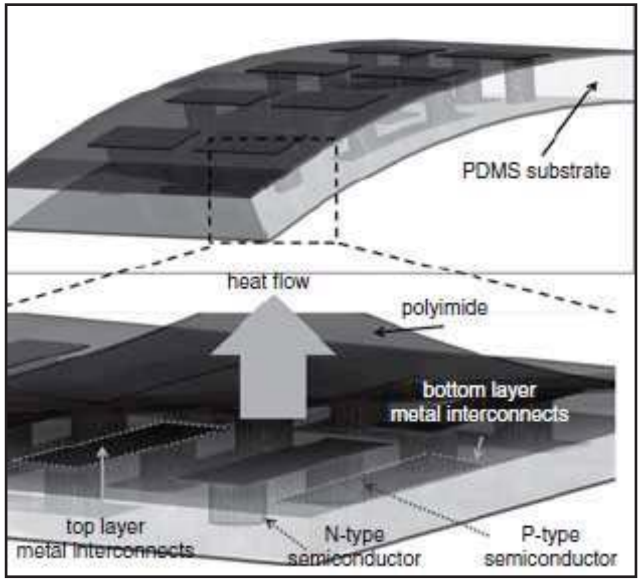


5.Comparison with conventional TEGs (I)

Francioso et al., J Power Sources (2011)



Jo et al., Electron Lett (2012)



Delaizir et al.,
Sensor Actuat A-Phys (2012)

5.Comparison with conventional TEGs (II)

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Device		(Francioso et al. 2011)		(Delaizir et al. 2012)		(Jo et al. 2012)		**This study**	
Design		Lateral/lateral		Vertical		Vertical		**Lateral/lateral**	
Substrate		polyimide (PI)		PI		PDMS		**PDMS/glass**	
Inactive to active Material ratio		0.23		0.88/3		1.75/27.4		**1.47**	
Resistance/ leg pair [Ω]		3.8×10^3		394		21.25		**~10^4**	
Seebeck cf./ leg pair [µV/K]									
Material	Device	409	108	350	210	-	93	**235**	**~170**
Max. el. Power/ leg pair [µW] (ΔT=30K)		0.00019		0.05		0.56		**0.0013**	
Efficiency factor [$\mu W/K^2cm^2$]		1.6×10^{-5}		$1.8 \times 10^{-3}/1.3 \times 10^{-3}$		$2.8 \times 10^{-3}/1.0 \times 10^{-4}$		**1.299×10^{-4}**	
Leg pairs/ area [cm^{-2}]		~76		~33/25		4.5/0.16		**~90**	

From: Glatz et al., J Microelectromech S (2009)

6.Conclusions

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- LIFT presented as **additive direct-write** tool for **microfabrication**
- Demonstrated **working thermoelectric generator** (TEG) on **polymer-coated** substrate
- Key results:
  - Sequentially LIFTed device elements
  - Seebeck coefficient/TC: **~170µV/K**
  - Performance comparable with other lateral-lateral TEGs on polymer

- **Future**: transfer of more complex TE materials, use of fully flexible substrate, Metal electrodes via LIFT

Acknowledgements

Thanks!

We acknowledge the technical support of the Novel Glass & Fibre group.

This work was kinldy funded by the FP7 framework European project 'e-LIFT' (n°247868 - FP7-ICT-2009-4)

LIFT at the University of Southampton: http://www.orc.soton.ac.uk/lift.html