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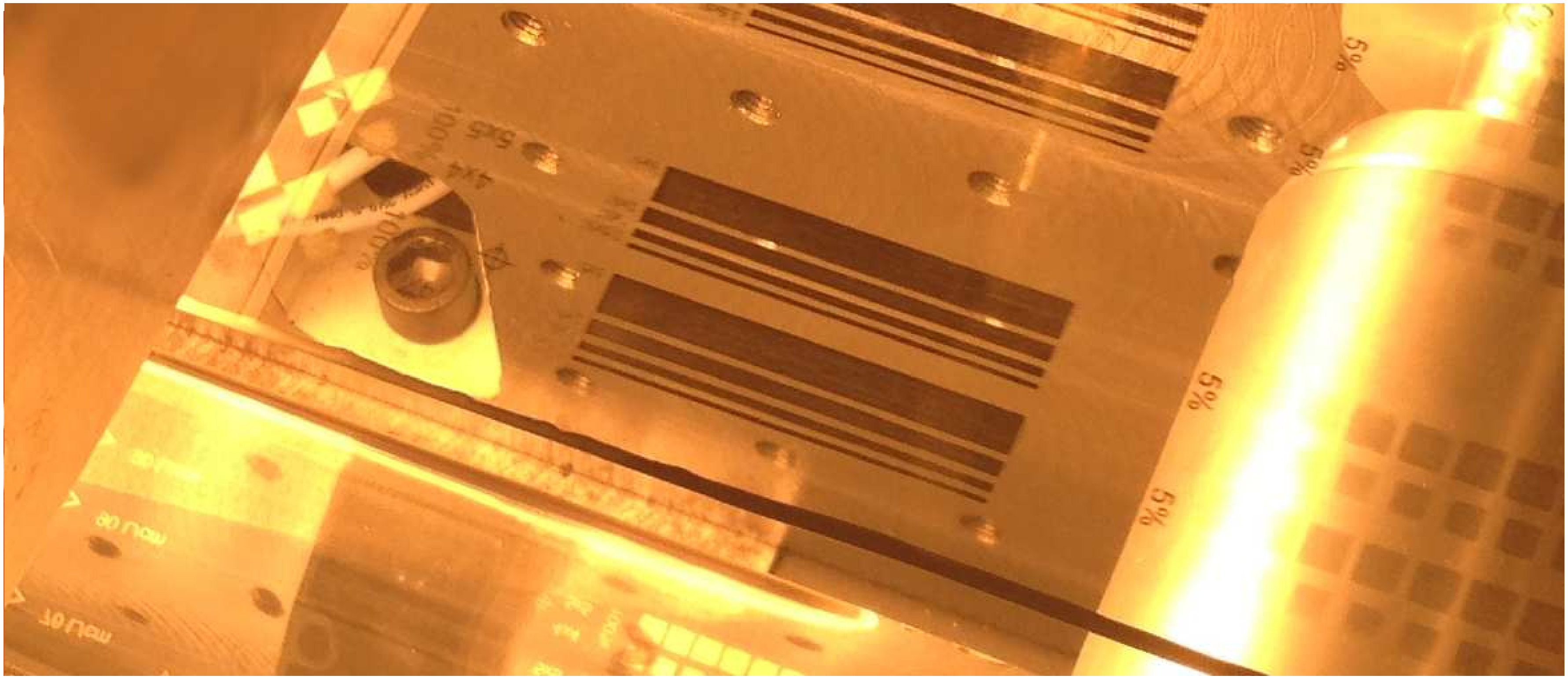

Infrared for Drying and Sintering of Printed Electronics Materials Valley March 13th 2014

Jürgen Weber, Heraeus Noblelight GmbH

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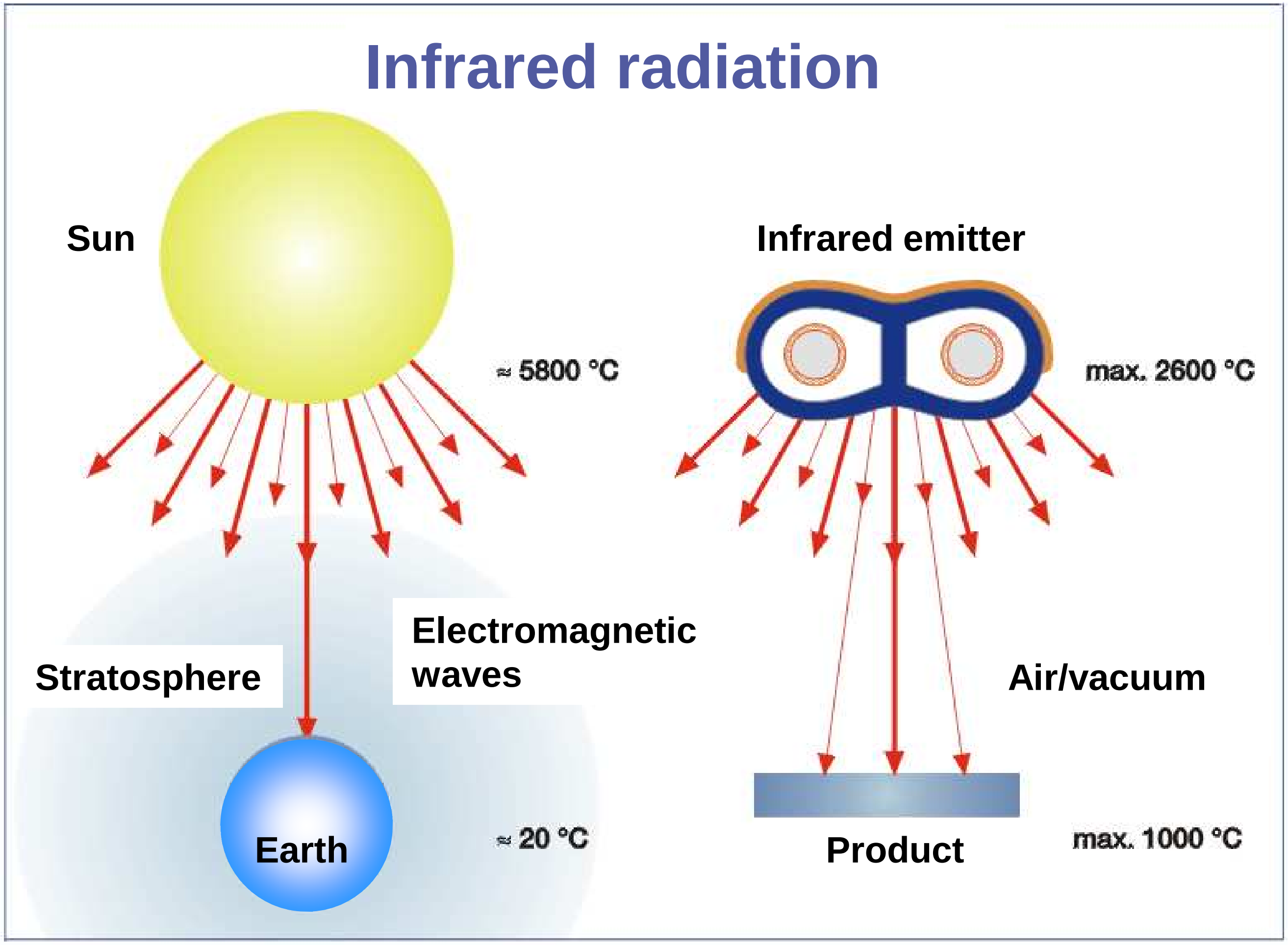
Infrared Radiation



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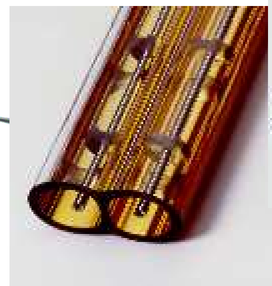
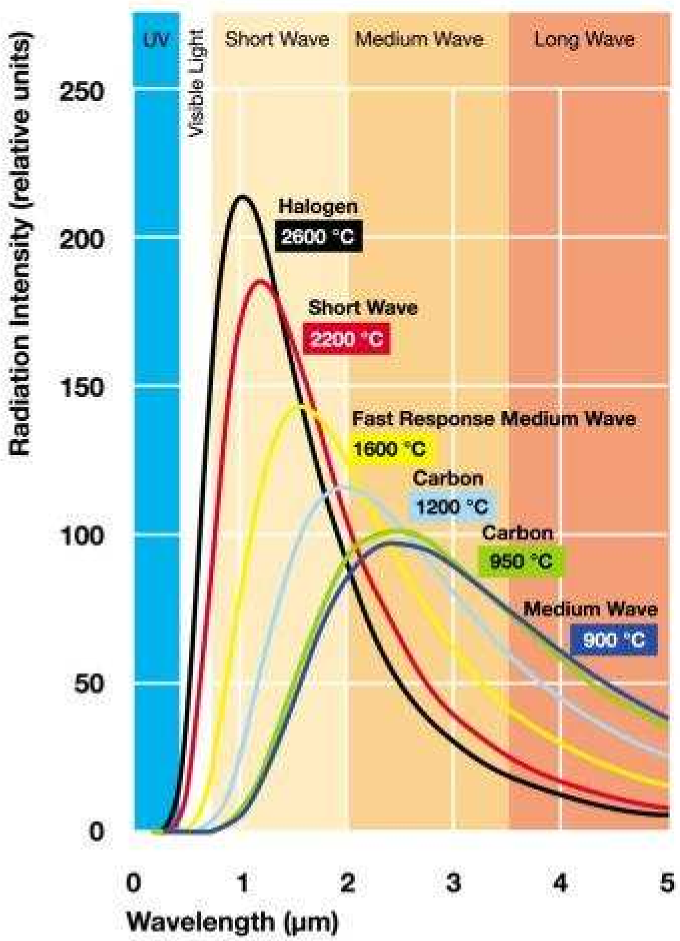
Infrared Emitters



	InfraLight	Short Wave	Fast response medium Wave	Carbon round	Twin	Medium Wave
Max. Power/m²	250 kW	200 kW	150 kW	100	150 kW	60 kW
Filament - temperature °C	2300 -2600	1800 -2400	1400 -1800	1200	1200	800 -950
Reaction time	1 s	1 s	1 - 2 s	1- 2 s	1- 2 s	1- 4 min

Infrared: Spectral Radiation Distribution



Spectral Radiation Distribution at the same electrical power ratings

Application Printed Electronics: Definition.

- **Printed electronics**

  is a set of printing and coating methods used to create electrical devices on various substrates.

- Heraeus Noblelight Infrared division is focused to generate the function via drying and sintering of organic and anorganic inks and coatings.

So, why Printed Electronics ?

→ Markets and applications.

Printed Electronics is …

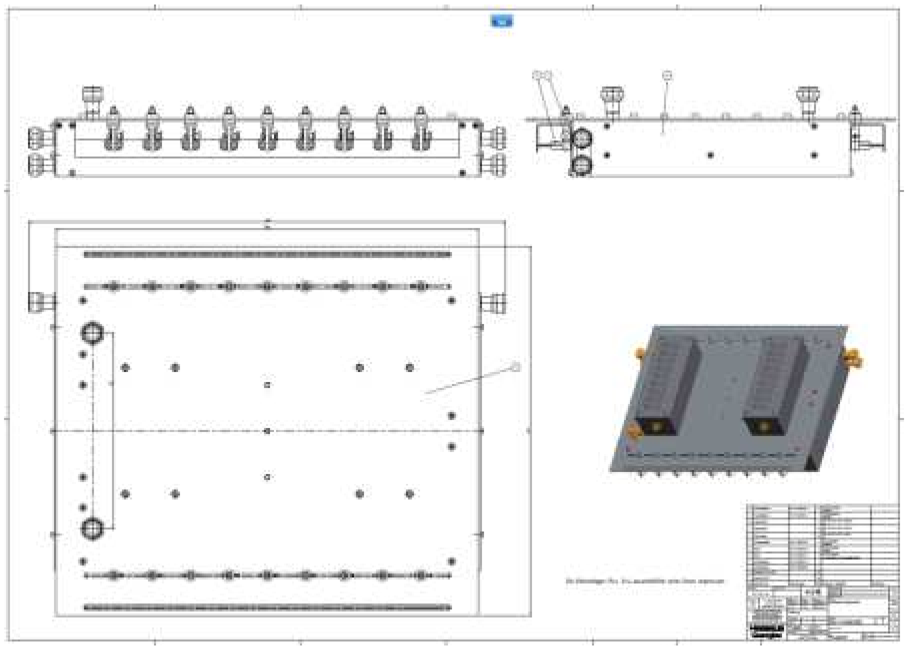
- A complementary technology to conventional semiconductors,
- A niche market having > 3 bill. US$ sales this year and expected > 8 bill.$ (2023),
- Thin and flexible,
- Universally applicable with well-known printing techniques on various substrates,
- **Low-cost (fits in existing equipment and supply chain),**
- **High-volume (fast, mass market potential).**

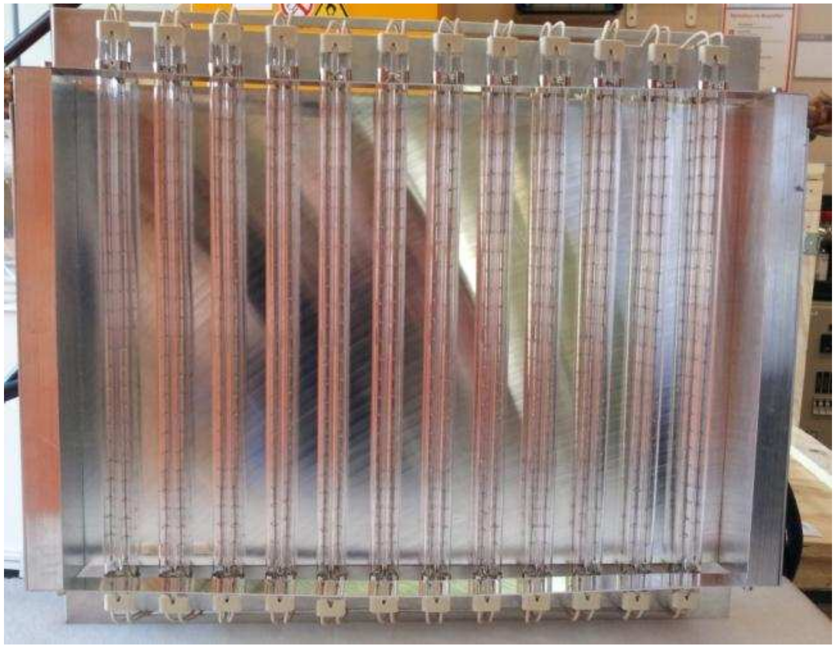
Critical parameters for IR drying and sintering

- Emitter power density
- Peak wavelength (filament temperature)
- Reflector technology (metals and quartz) for best efficiency
- Distances: emitter – product -- back reflector
- Reflection and absorption properties of ink and substrate
- Homogeneity of irradiation

- Depending on customer PE process (ink, substrate, web speed, …), we have to adjust all of the parameters
- Our goal: IR recipe for any PE process
- Numerical simulation helps to find best set-ups in terms of efficiency and homogeneity

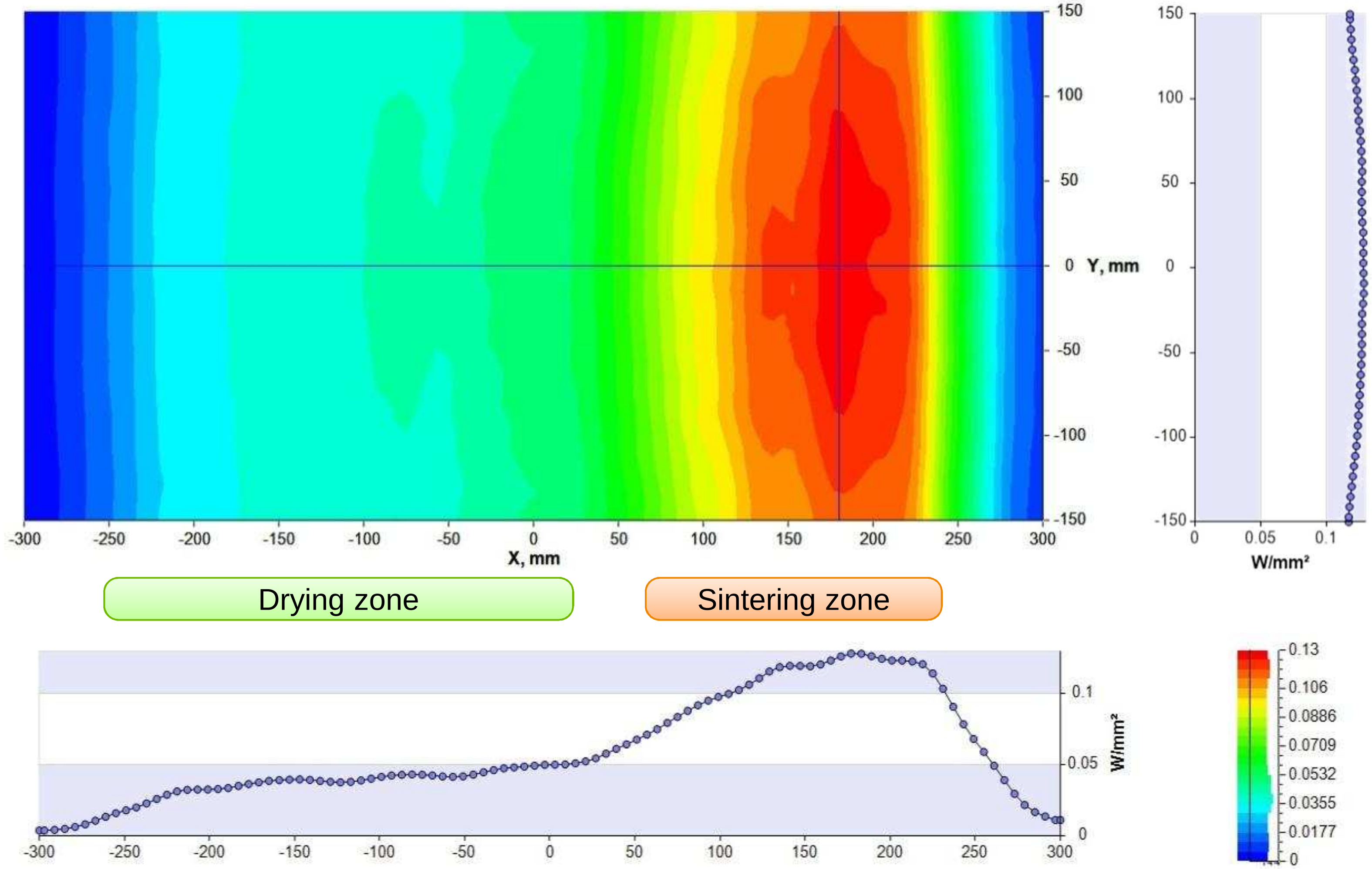
Test module design



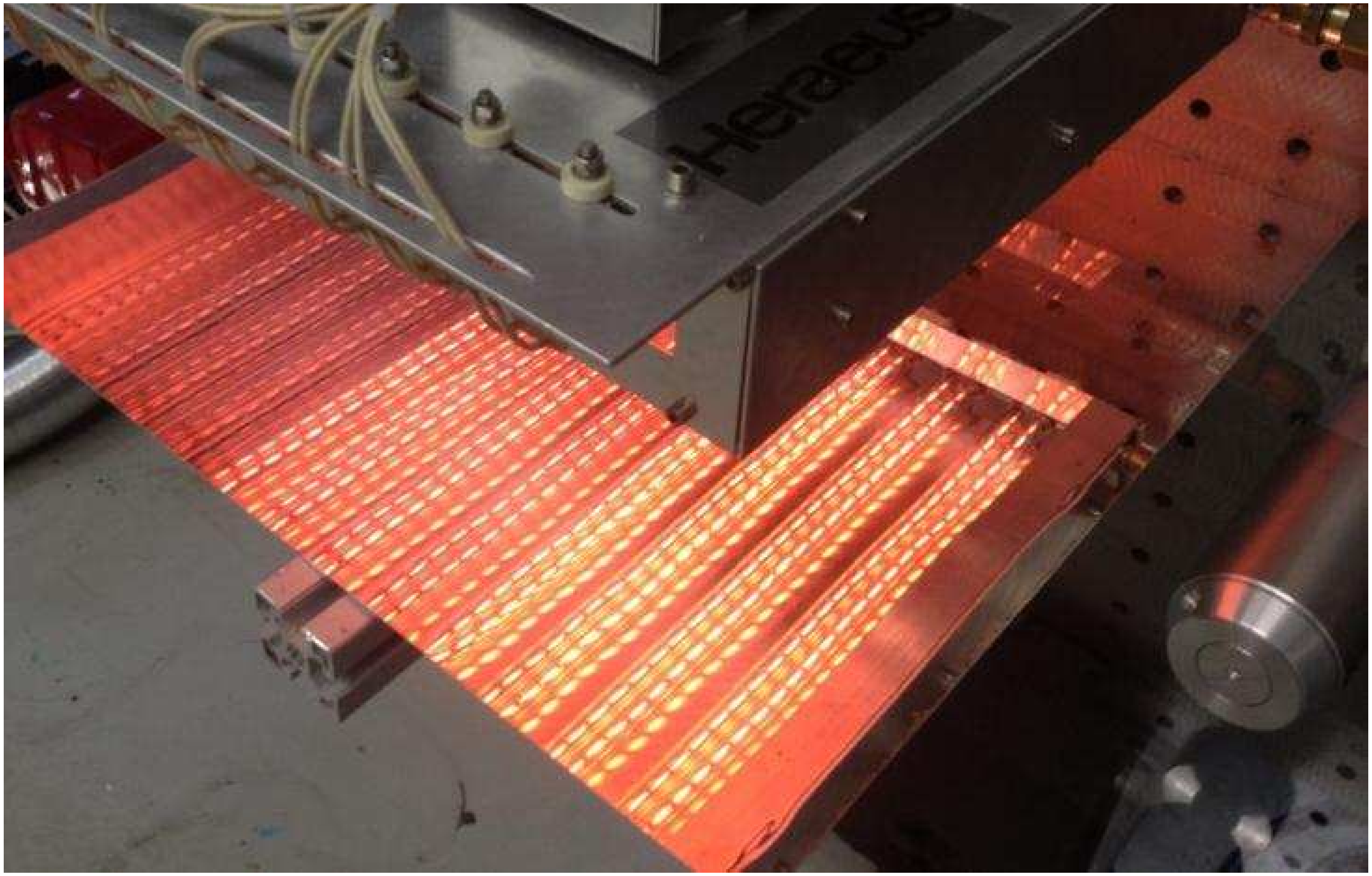


- Based on advanced numerical simulations

Drying and sintering zone in one module
Simulated infrared power density on PET substrate



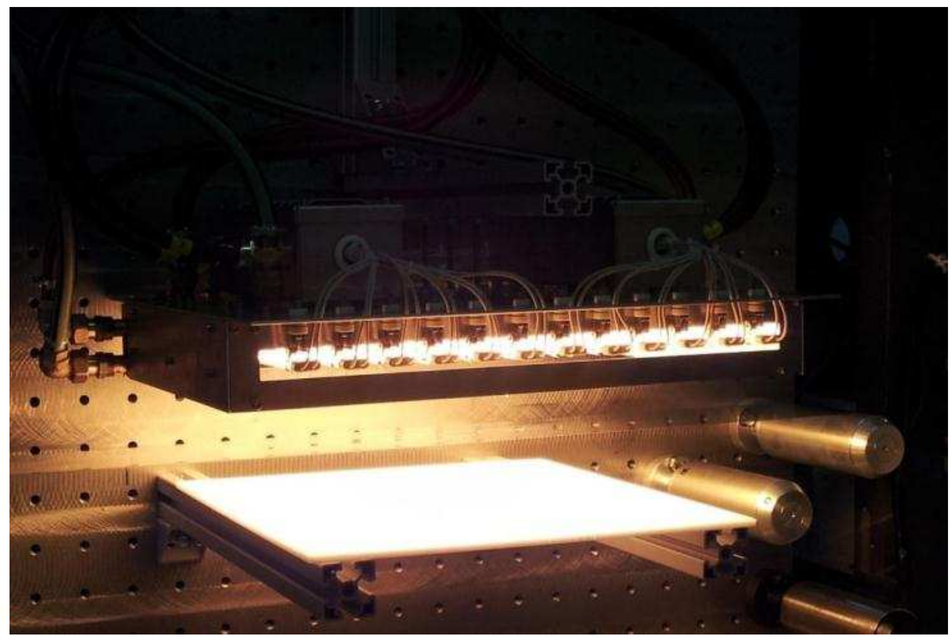
Drying and sintering zone in one module



Reflector technologies for IR and UV solutions

- Heraeus Noblelight offers sophisticated reflector technologies
  - Directly located on the emitter: Gold, Quartz Reflective Coating QRC® Nanoreflector
  - Behind the substrate: Al, QRC®, wavelength converter, others on request.

QRC® (quartz reflective coating)

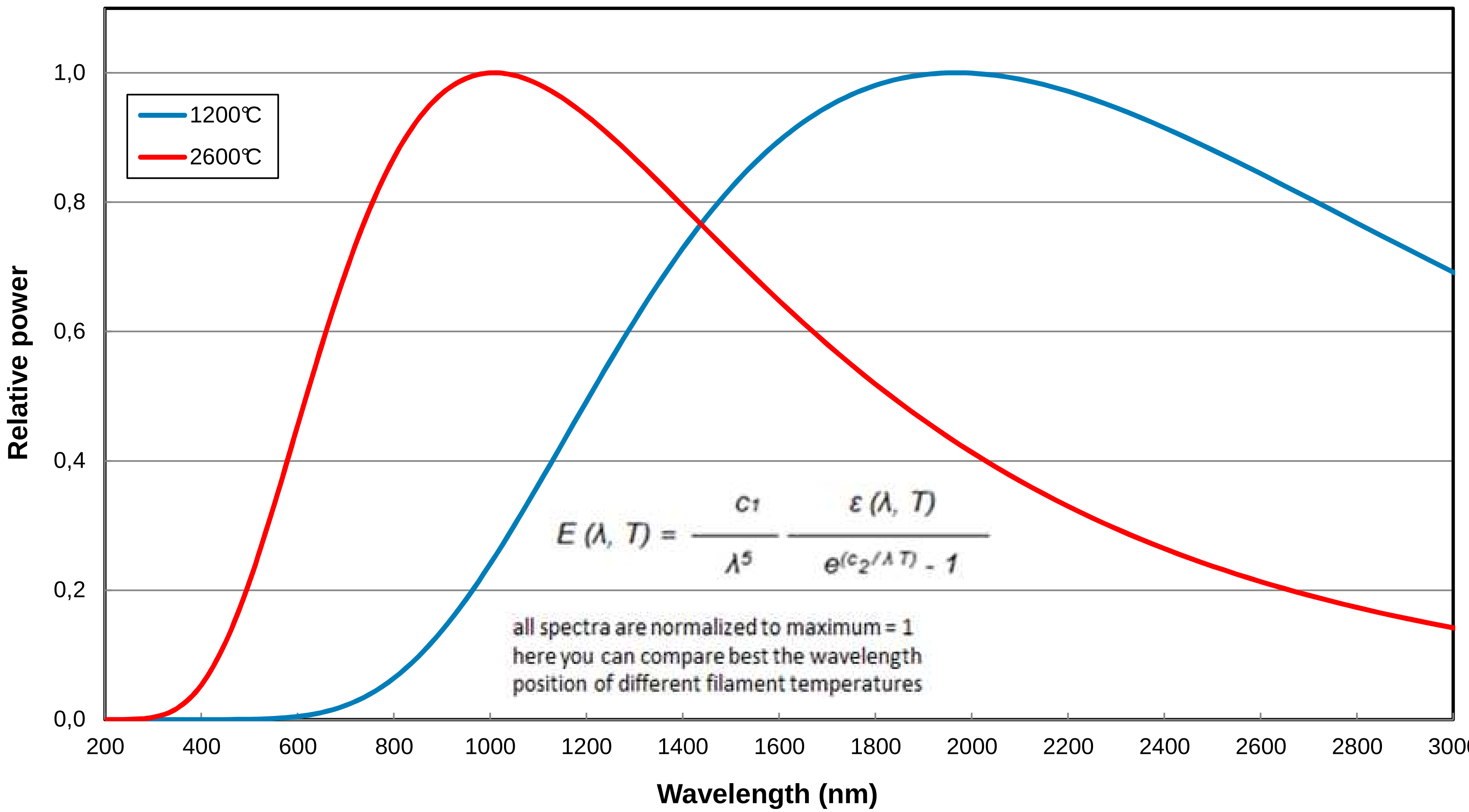


Energy intensity depends on filament temperature

T K	T °C	UV 200 - 380 nm	VIS 380 - 780 nm	IR-A 780 - 1400 nm	IR-B 1400 - 3000 nm	IR-C 3000 - 5000 nm
800	527	0,0%	0,0%	0,4%	21,5%	26,2%
1000	727	0,0%	0,0%	2,2%	37,3%	23,9%
1200	927	0,0%	0,0%	5,7%	45,6%	22,4%
1400	1127	0,0%	0,2%	11,1%	50,7%	18,8%
1600	1327	0,0%	0,6%	17,4%	52,0%	15,6%
1800	1527	0,0%	1,5%	23,6%	50,9%	13,0%
2000	1727	0,0%	2,9%	29,1%	48,4%	11,1%
2200	1927	0,0%	4,8%	33,7%	45,3%	9,5%
2400	2127	0,0%	7,1%	37,2%	42,1%	8,0%
2600	2327	0,0%	10,0%	39,7%	38,9%	6,9%
2800	2527	0,1%	13,1%	41,3%	35,8%	6,1%
3000	2727	0,2%	16,4%	42,0%	33,0%	5,4%
3200	2927	0,3%	19,8%	42,1%	30,4%	4,8%
3400	3127	0,5%	23,2%	41,7%	28,0%	4,3%

$$E(\lambda, T) = \frac{c_1}{\lambda^5} \frac{\varepsilon(\lambda, T)}{e^{(c_2/\lambda T)} - 1}$$

Wavelengths



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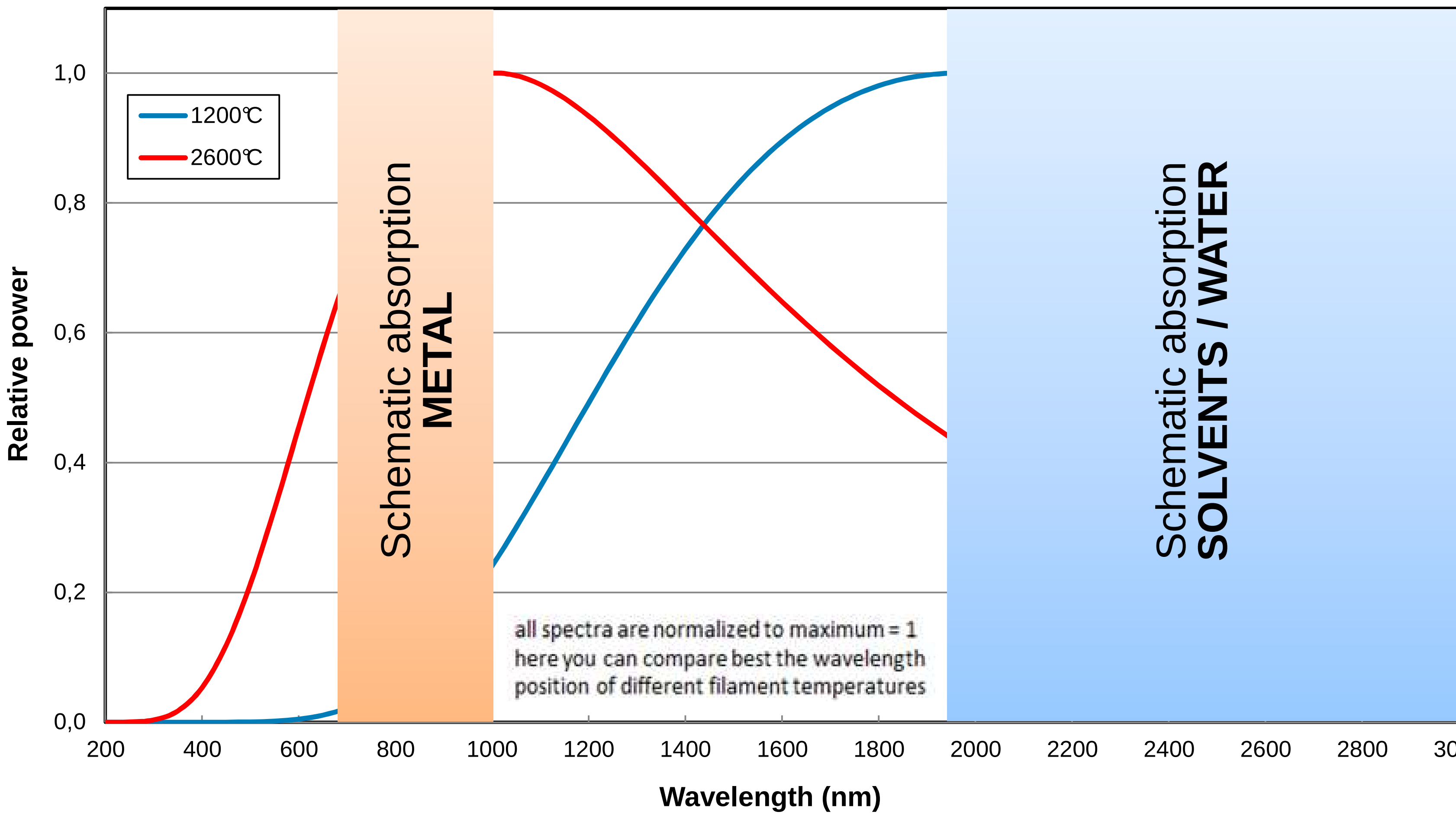
Wavelengths



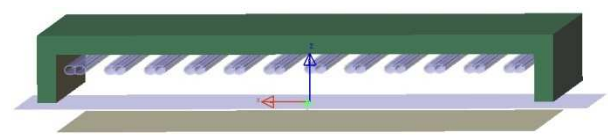
Drying and sintering zone in one module

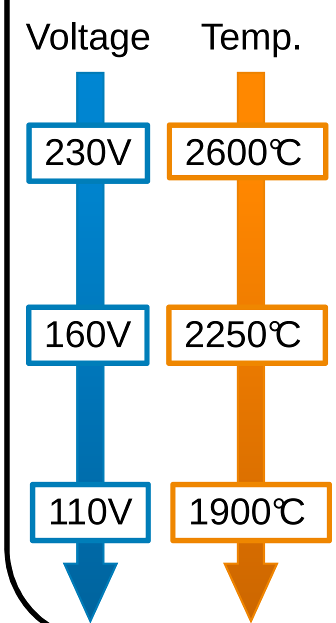
Solution 1

- Different emitter types in one module (e.g. Carbon + SW)
- Full spectrum of Heraeus emitters can be used

Solution 2

- Only one emitter type
- Intelligent control unit



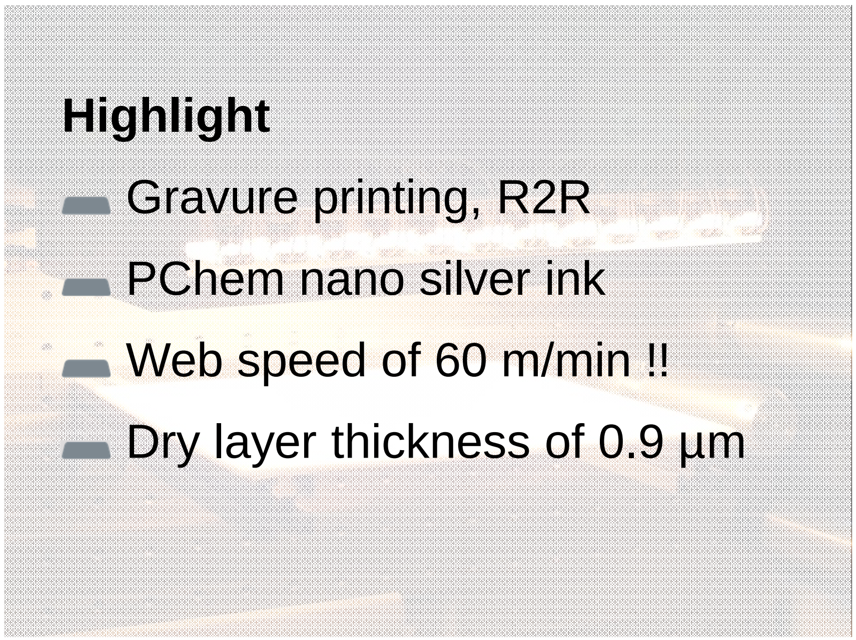


- 7 channels → 7x 2725 W
- ~**120 kW/m²**

- 12 channels → 12x 1532 W
- ~ **120 kW/m²**

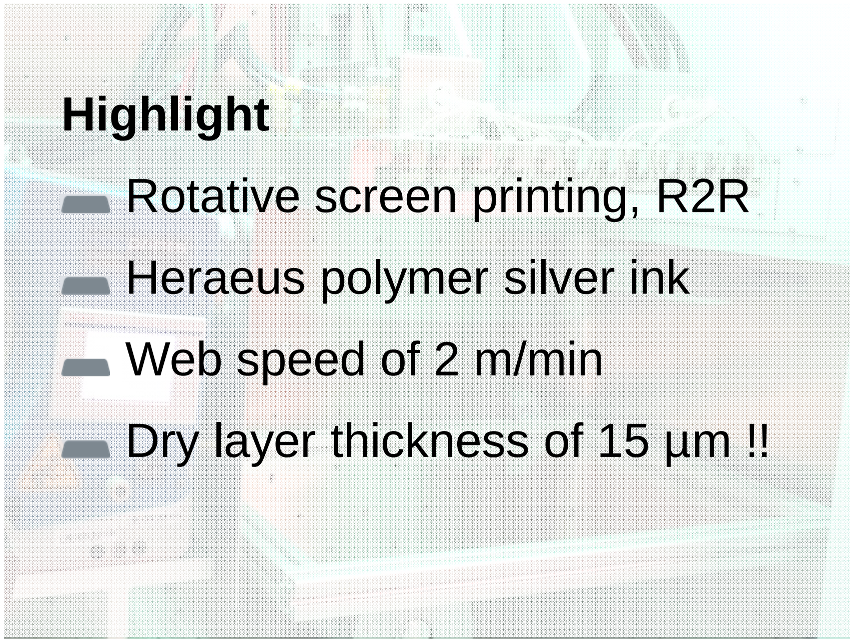
- 22 channels → 22x 848 W
- ~ **120 kW/m²**

Tests



Highlight

- Gravure printing, R2R
- PChem nano silver ink
- Web speed of 60 m/min !!
- Dry layer thickness of 0.9 µm



Highlight

- Rotative screen printing, R2R
- Heraeus polymer silver ink
- Web speed of 2 m/min
- Dry layer thickness of 15 µm !!

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All Tests done so far – to be continued!

Printing technology	**Ink (Supplier)**	**Substrate**	**Web speed [m/min]**	**Infrared power density [kW/m^2]**
Screen	PEDOT PSS (Heraeus Clevios)	PET	3,8	30
Rotative screen	Ag polymer (Heraeus)		3	25
Inkjet	Au resinate (Heraeus)	glass	0,2	100
	nano Ag	PEN	3	120
			60	220
			14	100
	dielectric		3	115
Gravure	nano Ag	PET	60	80
Flexo	Ag flakes		20	80

Heraeus

Speed up production processes significantly: Examples of drying Clevios™ by infrared

- **Clevios™ F ET** is an aqueous type ready-to-use coating formulation to prepare highly conductive and transparent coatings, e.g. for touch panel applications.
- **Clevios™ S HT** is a printing paste based on glycolic solvents. Screen-printing can be used to pattern transparent conductive electrodes on plastic film substrates, e.g. for touch sensors and switches.

- Drying Clevios FET, S2S, in a standard hot air oven typically needs for 200-300 ohms/sq.:
  15min@130℃

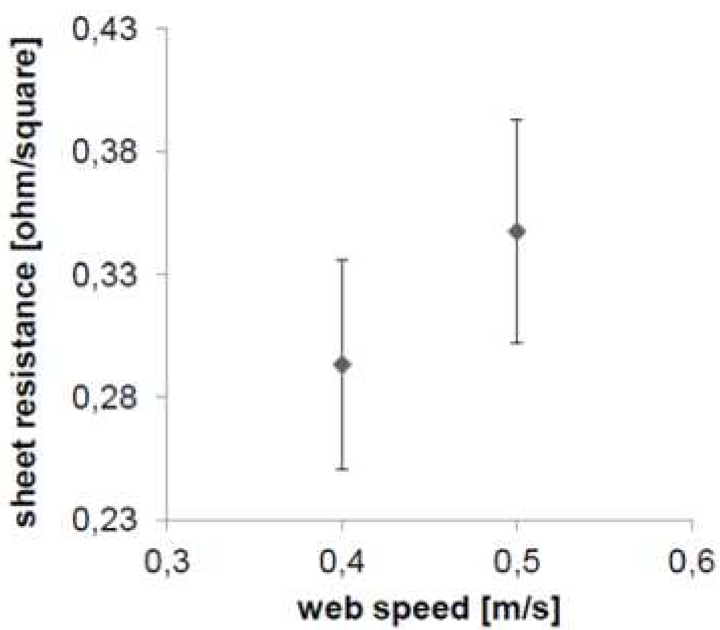
- Infrared examples for comparison, R2R, PET film substrate (Melinex 505, 175µm):

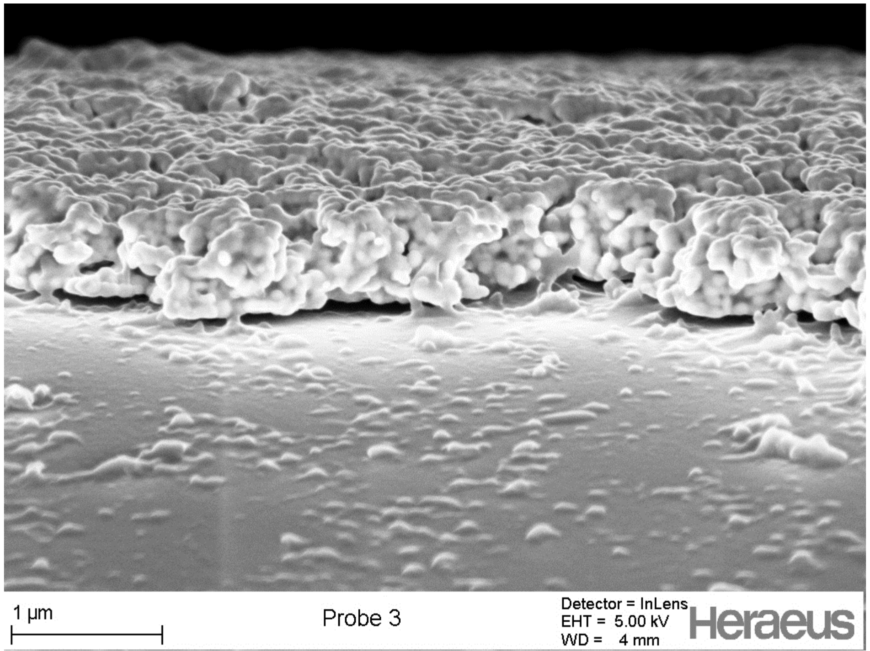
Sample	Wet-film	web speed	Drying time	Surface Resist
Clevios F ET	12 micron	5.5 m/min	**5,5 sec**	150 Ohm/sq
Clevios S HT	12 micron	4.6 m/min	**6,5 sec**	780 Ohm/sq

- **Infrared is an enabling technology for mass production R2R.**

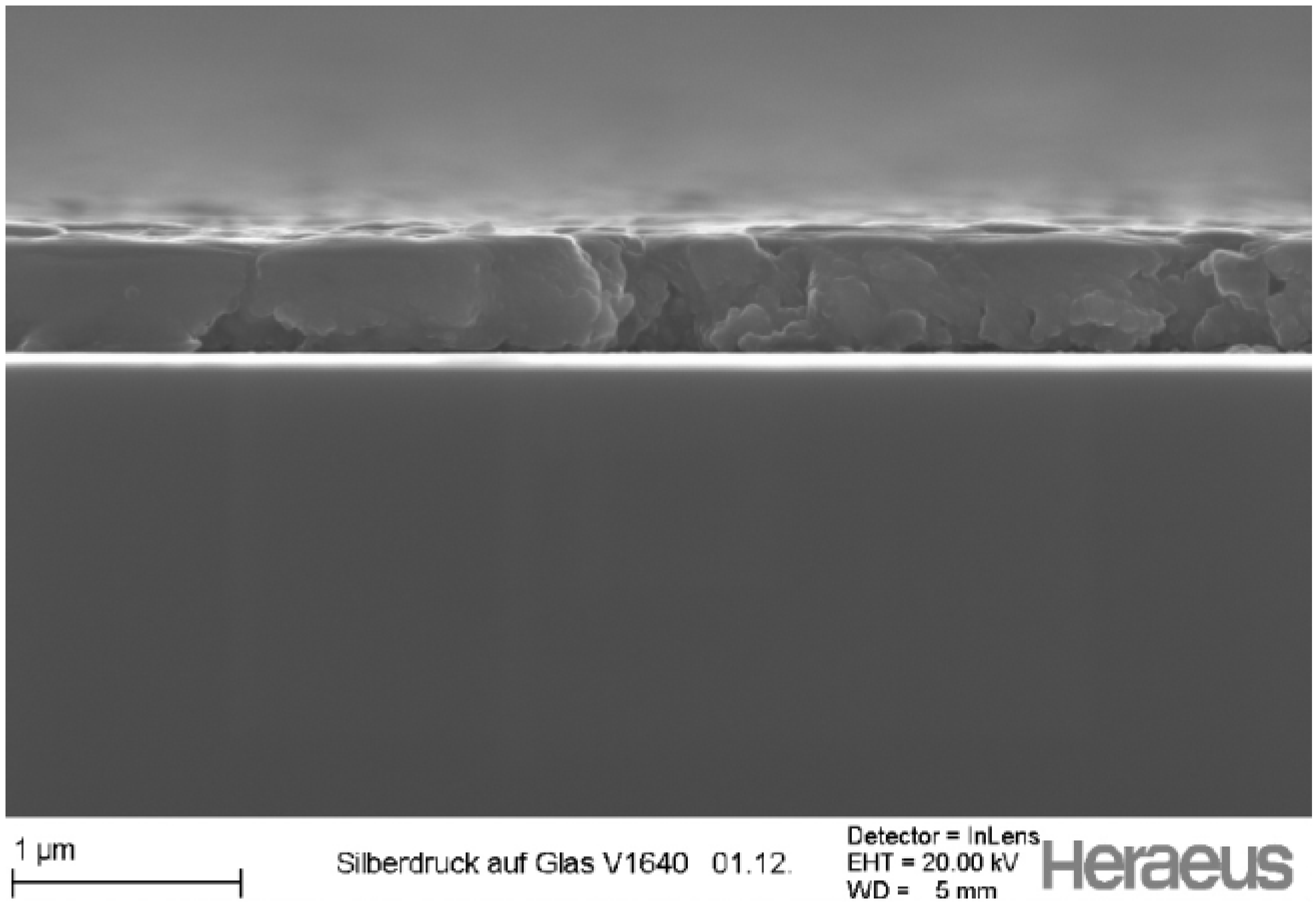
Infrared reaches highest level of conductivity: < 1 ohms/sq.

- Nano Ag (Sunchemical EMD5603) on PEN.
- Porous silver metal structure is fully sintered in depth.
- Web speed up to 60 m/min R2R, sinter time for inkjet samples < 1 s !

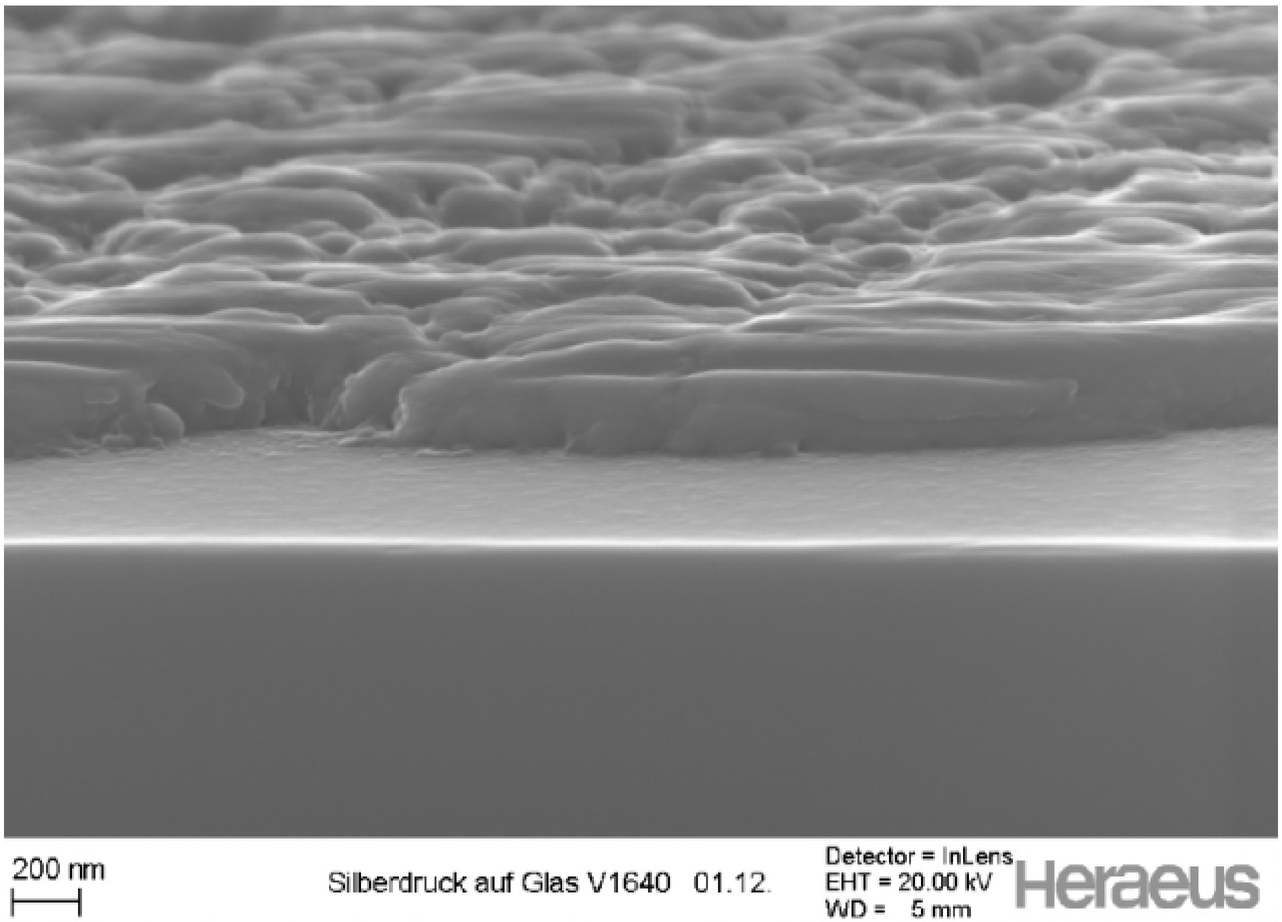




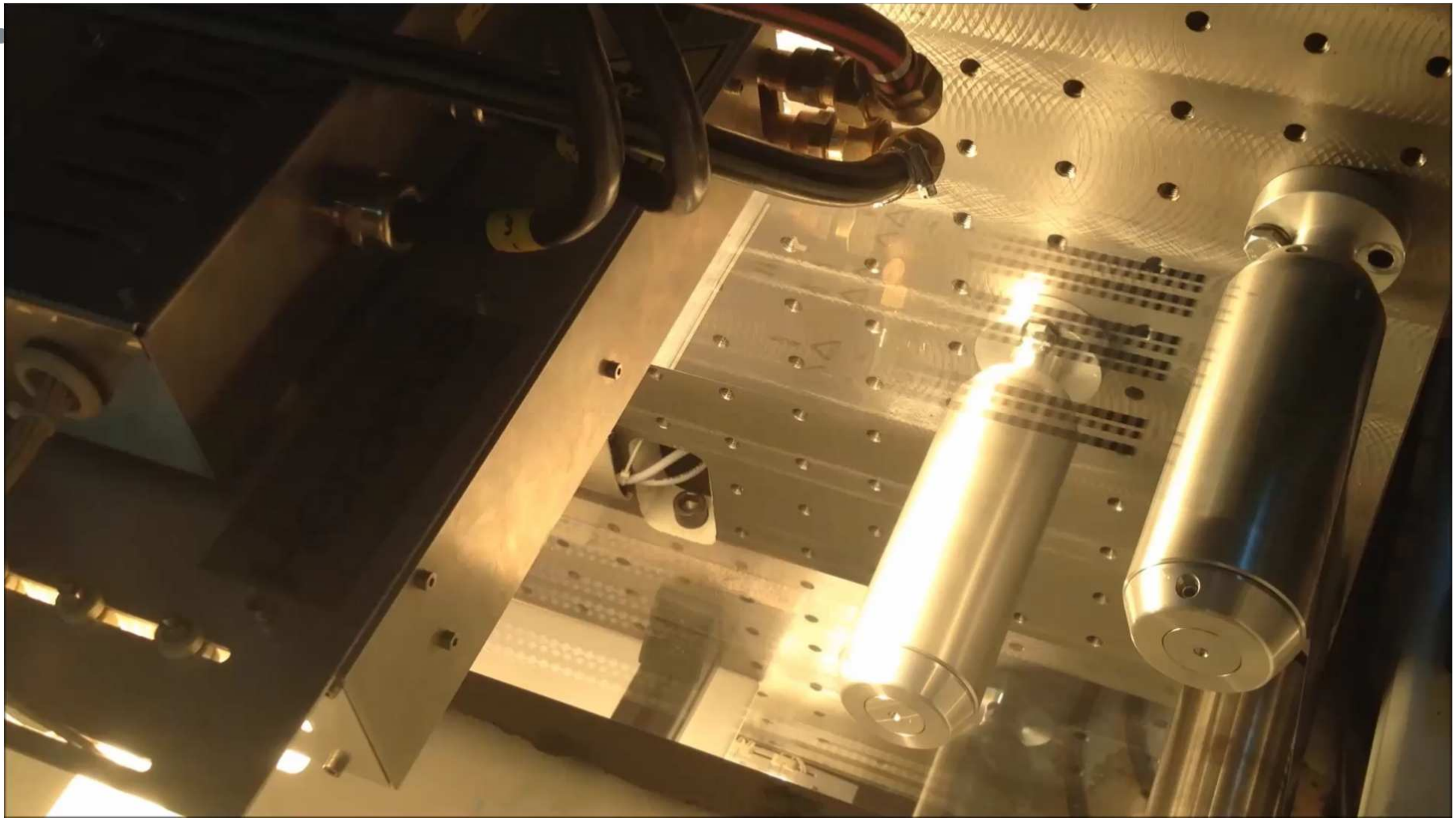
Ag screen print on glass: 350℃, 150 sec



Ag screen print on glass, densified porous structure -> bulk



Movie: Ag gravure printing on PET



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Heraeus One-Stop-Solution for materials and drying/sintering

Joint flyer

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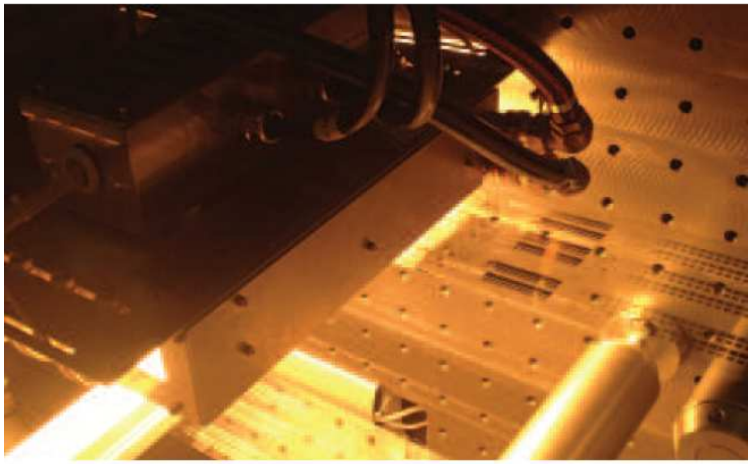


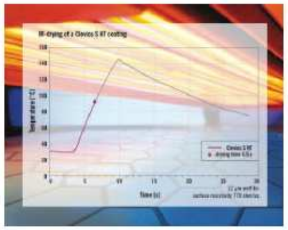
Heraeus Products for Printed Electronics

Substrates, Inks and Special Light Sources for Drying and Sintering

Printed electronic components and printed features of electronic products are very much on the increase, providing RFID (radio frequency identification), as integral features of telephone- and credit cards (smart cards), providing protection against copying or as security features in identity cards and passes. To produce such printed electronic components, organic or metallized inks are applied to plastic foils, paper or glass. By curing, drying and sintering, the required conductive properties are achieved and at the same time the coating is firmly joined to the base material.

All conventional printing processes, such as screen printing, inkjet, gravure and Flexo, can be used to produce printed electronic components. The inks used are organic or metallized inks and these can be used with many materials such as paper, plastic foil or glass. Curing, drying and sintering are processes necessary to obtain the required conductivity or the semi-conducting or dielectric properties. These processes can be carried out by UV emitters, LEDs, flash lamps, hot air ovens or infrared systems.
Heraeus offers comprehensive solutions all around the printed functionalities. Resinates from Heraeus Precious Metals, which serve as base layers, conductive polymers from Clevios and a new Infrared system from Heraeus Noblelight for highly efficient drying and sintering.

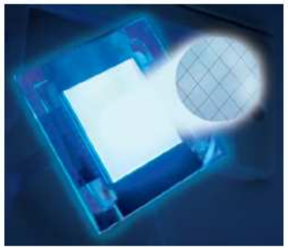
Foto: Infrared heaters are curing inks on foils



Clevios™

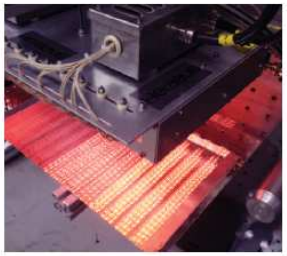
Clevios conductive polymers
Quick dried Clevios™ Conductive Polymers are printable, flexible and transparent materials and formulations for use as electrodes and hole transport materials in electronics.

- Applications for Clevios™ include touch panels, OLED display and lighting and Organic Solar Cells.
- Sheet resistivity <150 Ohm/Sq. can be obtained.
- Suitable for roll-to-roll processes.
- Can be printed and patterned.



Resinates for ....

With over 40 years of expertise in the thick film business, Heraeus offers resinates for low temperature applications onto glass. These resinates are characterized by high conductivity, smooth surface, low temperature sintering conditions, good adhesion, low sintered film thickness, ultra-fine line resolution and no outgassing after sintering. Application method can be either screen printing or gravure offset printing. The new generation of resinates allow to apply a highly conductive base layer directly on the glass substrate, then followed by sputtered ITO layers or printed conductive polymers.



Customized Infrared system
Infrared emitters transfer energy in a contact-free manner and generate energy only in the product to be heated. They can be excellently matched with different functional materials and substrates in terms of wavelength, power and shape. Very fast response times minimize material damage in the event of unexpected feed belt stoppage or breakage. Modern numerical methods such as Ray tracing and Computational Fluid Dynamics (CFD) are used to ensure that heating is as homogenous as possible. The energy distribution over the material surface can be optimized, for example, by carrying out simulations prior to installation. Sophisticated reflector technology also helps to ensure that the energy is applied in the best way possible.

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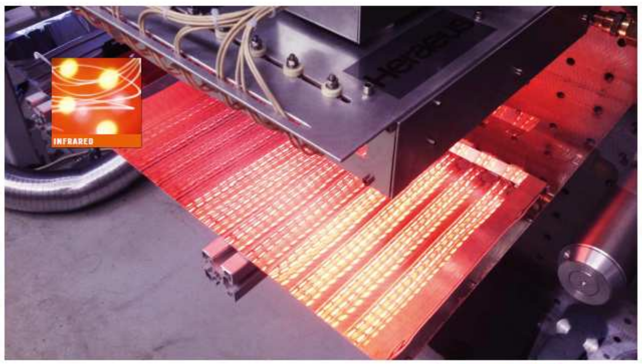
LOPE-C exhibition 2013 at Munich

The 5th LOPE-C has established itself as an international market place for printed electronics:
With specific applications, successful business deals and an intensive dialog between industry, economy and research. The International Exhibition and Conference for Organic and Printed Electronics in Munich drew to a very successful close with some 1,800 participants from around 40 countries (110 exhibitors from 19 countries). That means an increase of just over 20 per cent more than last year.

Source: www.lope-c.com

Impressions from the LOPE-C 2013 in Munich

- Poster and flyer for your information, pls. feel free to take a copy !



Tailored Infrared Tool

Drying and Sintering Processes in Printed Electronics

Jürgen Weber, Oliver Weiß, Holger Zissing, Heraeus Noblelight GmbH, Hanau
Enrico Sowade, Frank Siegel, Kalyan Yoti Mitra, Peter Ueberfuhr, Chemnitz University of Technology
Reinhard R. Baumann, Chemnitz University of Technology and Fraunhofer Institute for Electronic Nano Systems (ENAS)

Printed functional materials need intelligent solutions for print drying and sintering. For this purpose a new infrared tool for post-treatment of roll-to-roll printed functionalities was qualified. Numerous experiments with different printing techniques and test setups were carried out to obtain optimal drying and sintering process results. All experiments were supported by advanced numerical simulations.

Ray Tracing calculations were used for optimizing the setup geometry and to achieve the infrared power density on the substrate surface needed for a specific process. Figure 1 shows a process area splitted into a drying zone generated by an emitter power density of 50 kW/m², and a sintering zone with an emitter power density of 150 kW/m².

For inkjet tests the nano ink Jet Silver U5603 (Suntronic) was printed on PEN foil (175 µm thick) using a Dimatix DMP-2831 printer. Samples were dried and sintered in one R2R process step with a web speed of 60 m/min using the tailored Heraeus infrared tool with an emitter power density of 220 kW/m². A corresponding sample (fig. 2) has a dry layer thickness of 0.9 +/- 0.2 µm and a sheet resistance of 0.32 Ω/sq.

The table gives an overview of all combinations of inks, printing techniques and substrates successfully processed so far using Heraeus infrared technology. This includes also a dielectric material usually cured by UV light. By adjusting the parameters of the infrared tool, optimum drying and sintering conditions for all combinations were achieved:

- Infrared power density in the range between 20 to 220 kW/m²;
- The peak emission wavelength varied between 0.9 and 2.0 µm (corresponding to emitter filament temperatures 1200 to 3000 °C);
- IR-drying and -sintering was realized with a web speed of 60 m/min, demonstrating the suitability of this method for mass production.

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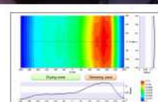


Fig. 1Ray tracing simulation: Infrared power density on PET substrate

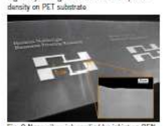


Fig. 2 Nano silver ink applied by inkjet on PEN

Printing technology	Ink (supplier)	Substrate	Web speed [m/min]	Infrared power density [kW/m²]
Screen	PEDOT PSS (Heraeus Clevios)	PET	3,8	30
Rotative screen	Ag polymer (Heraeus)	PET	3	25
Ink jet	Au resinate (Heraeus)	glass	0,2	100
	nano Ag (SunChemical)	PEN	3	120
			60	220
			14	100
	dielectric (Polyprocess)	PEN	3	115
Gravure	nano Ag (PChem)	PET	60	80
Flexo	Ag (DuPont)	PET	20	80

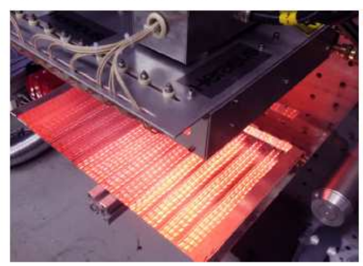
Tailored Infrared Tool for Drying and Sintering Processes in Printed Electronics

Today a wide range of potential applications for printed electronics and printed functionalities are under development and many young companies are working on the industrialization. Different printing technologies such as screen printing or inkjet printing are used for applying several types of inks, for instance organic and metal based ones, on different substrate materials (e.g. polymers, papers, glass). Next to the deposition of these materials with the appropriate printing technology, post-treatment processes such as curing, drying and sintering play a key role to evolve a function (e.g. conductivity, semiconducting or dielectric properties) of the printed layers. Today the kind of post-treatment technology strongly depends on the materials used as ink, the substrate and the processing: batch processing mainly applied in functional sheet-fed printing or primarily continuous processing in web-fed processing.

A unique infrared module including an intelligent control unit can manage nearly all important requirements, e.g.: emitter power density, homogeneous energy intensity on the substrate, web speed R2R, peak wavelength corresponding to emitter filament temperature, reflector technology (metals and quartz) for efficiency, equipment cooling, reflection and absorption properties of ink and substrate and some more important like the distance between emitter and product.

With our technique it is not necessary to change emitters, modules or other equipment between different applications. This increases productivity tremendously by managing different applications with one tailored infrared tool for drying and sintering processes in Printed Electronics.

Using Heraeus technology it is possible to manage the process complexity in two ways. At first, the infrared module can be equipped with one kind of infrared emitters only; an intelligent control unit manages the different operation conditions for different application requirements. At second, a drying and a sintering zone in one infrared module can be achieved by using two different emitter types, one type for each heating zone.



Features

- matching to ink, substrate and printing technology in two possible ways
- selection of infrared emitters exactly to required wavelength and power or
- intelligent control unit enables matching to different applications

Technical Data

- infrared power density in a range between 20 and 220 kW/m²
- emitter filament temperature of around 1,200 to 3,000°C
- web speed up to 60 meters per minute

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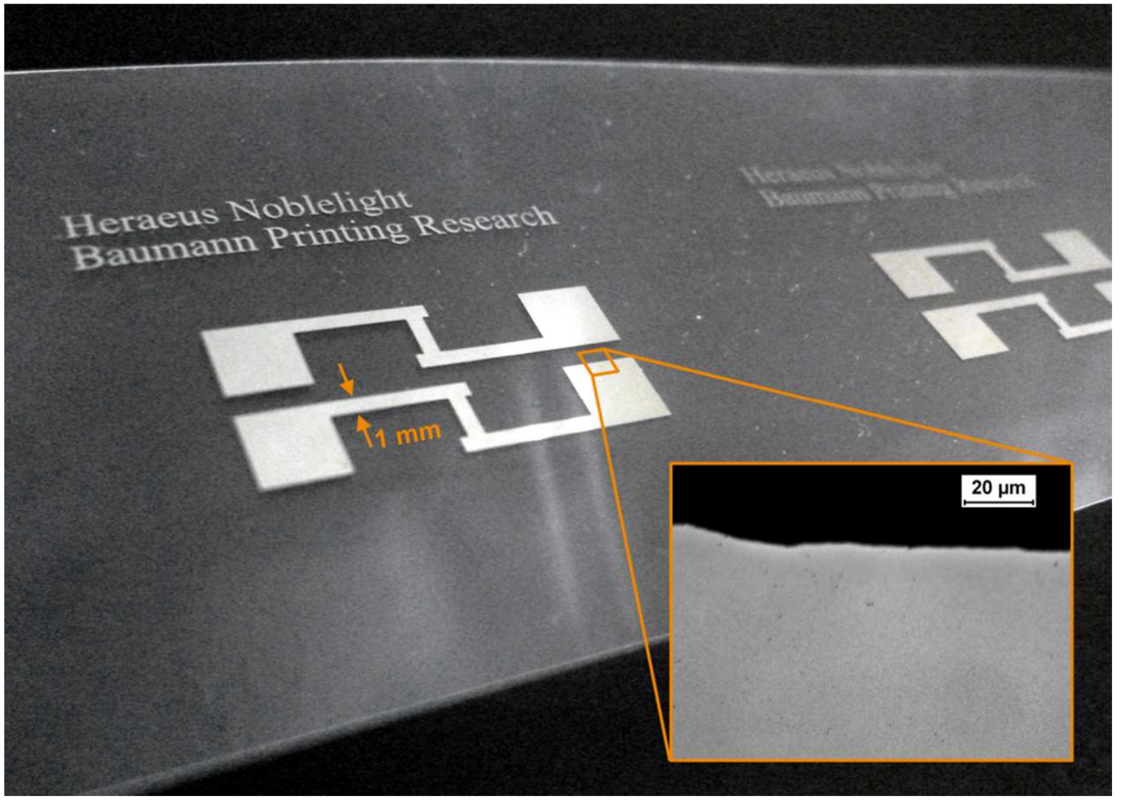
Congratulations to the Heraeus team !

- WW Heraeus Product Innovation Prize 2013, Top Five.

THANKS FOR YOUR ATTENTION !!!



Picture: inkjet printed nano silver ink, web speed 60m/min

Heraeus

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