MIRSURG

Mid-Infrared Solid-State Laser Systems for Minimally Invasive Surgery

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Specific Targeted Research
Theme 3: **Information and Communication Technologies (ICT)**

D4.2: Comparison of the mid-IR delivery system performance with high power ns pulses and ps pulse trains at 6.45 µm

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Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

1. Background

The objective for this deliverable was to test our IR delivery system with the 6.45 μm laser sources developed by the project partners. In line with this objective, further transmission experiments have been done to select the most adequate laser fiber for future clinical applications.

2. Fiber coupling system

A fiber coupling system has been developed and tested with the hollow waveguides (HWG) and solid core fibers (Fig. 1). This coupling system was designed as a closed system in view of the possibility to use gas flushing for hollow waveguides. The purpose of flushing gas through the coupling system and the hollow waveguide is:

(1) prevention of particles from entering the distal end of the fiber and

(2) the potential to use inert gas to prevent optical breakdown associated with the high fluence in the focus of the beam at the fiber incoupling end.

At the exit end of the hollow waveguide the gas flush from the fiber prevents particles formed during tissue ablation to enter and damage the tip of the fiber.

Figure 1: Closed end stage use coupler.

However, this functionality proved to be impractical for bench testing since there was no open view on the lenses. The alignment with laboratory laser set-ups was challenging and difficult to control.

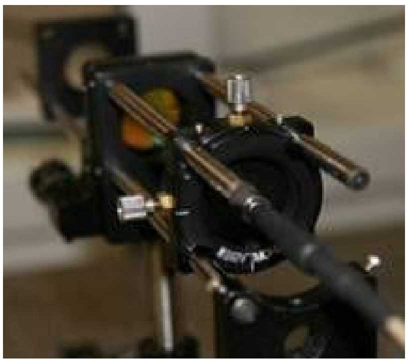

Figure 2: Open design coupler.

Therefore, another 'open' coupling system has been designed (Fig. 2) from off-the-shelf components which enables easy alignment. Due to the open structure, the beam can be observed throughout the optical system and the entrance of the fiber can be checked for irregularities and indication of degradation or damage. This new design does not have integrated flushing capabilities. Instead a tube with nozzle was positioned at the proximal end of the fiber to create a gas flow to prevent optical breakdown for both hollow waveguides and solid core fibers, and at the distal end, to prevent particles entering the hollow waveguide.

3. Selection of laser delivery fibers

For the project, the interest is in fibers capable to transmit 6.45 μm and made of materials that can be used in a clinical environment. Based on literature study, personal contacts with leading scientists in IR fiber development and companies producing IR fiber optics, we concentrated on the following sources for fibers that were used for initial feasibility studies and later with the 6.45 μm wavelength, see Table 1 and Fig. 3:

Table 1: IR fibers tested.

source	**website**	**type**	**material**	**brand**	**λ range**
Polymicro Technologies	www.polymicro.com	hollow			3, 10 μm
Omniguide	www.omni-guide.com	hollow		Omniguide	10 μm
CeramOptec	www.ceramoptec.com	solid	AgClBr	OptranMIR	4 - 13 μm

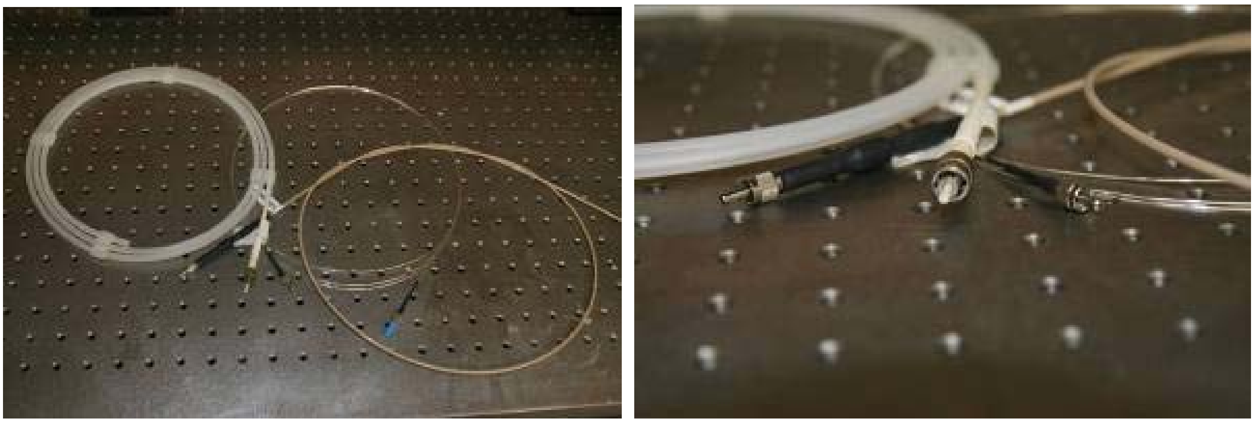

Figure 3: Overview of optical fibers tested: (left) from left to right, photon band-gap fiber, hollow waveguide, silver halide fiber, (right) close up of the SMA termination of the fibers.

Feasibility studies have been performed with the coupler and a CO_2 laser system to find the most suitable fiber for high transmission and practical use in a clinical environment to ablate biological tissue with various pulse/energy parameters.

4. Test results

The first test results are presented below. The fibers were cleaved at the input and output end to obtain a flat surface and the protective (plastic) coating on the outside was removed for several millimeters. The input end was terminated with a SMA adapter and connected to the coupler. The output end was positioned around 5 cm in front of an energy meter (Coherent). Using the x-y-z- adjustment capabilities, the coupler was aligned for maximum transmission. The transmission was tested in four conditions:

- straight
- 90° bend with a fixed radius
- 180° bend with a fixed radius
- 360° bend with a fixed radius

The measurements were performed 3 times and averaged. The transmission losses due to the lens surfaces of the coupler are around 10% and were corrected in the data. Pulses with an energy in the range of 10 to 50 mJ (20 to 100 µs pulse length) were launched into the fibers with a repetition frequency of 100 Hz (1 to 5 W average power, respectively).

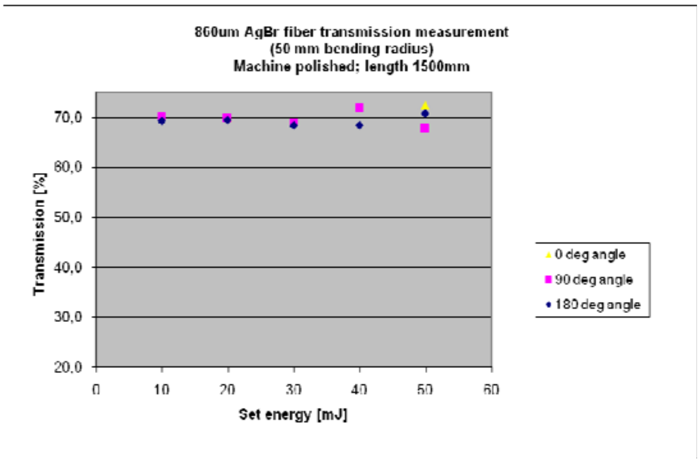

Figure 4: Silver halide fiber transmission.

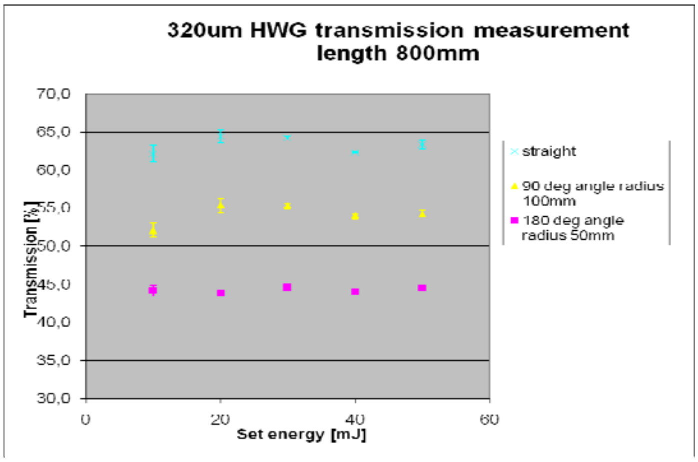

Figure 5: HWG fiber transmission.

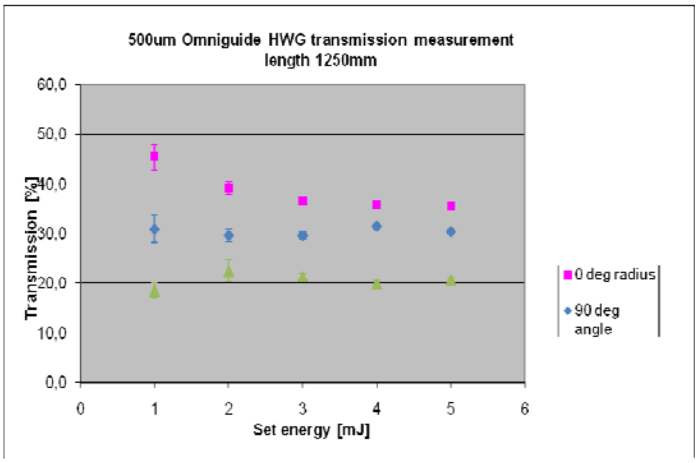

Figure 6: Omniguide band-gap fiber transmission.

The relatively low initial transmission results of the silver halide fibers (~50%) are ascribed to the irregularities at their ends and the lack of antireflection coatings (see Fig. 7). There were no adequate polishing capabilities at UMC at that time. After obtaining polishing equipment, new transmission measurements were performed, giving an increased transmission of up to approximately 70%.

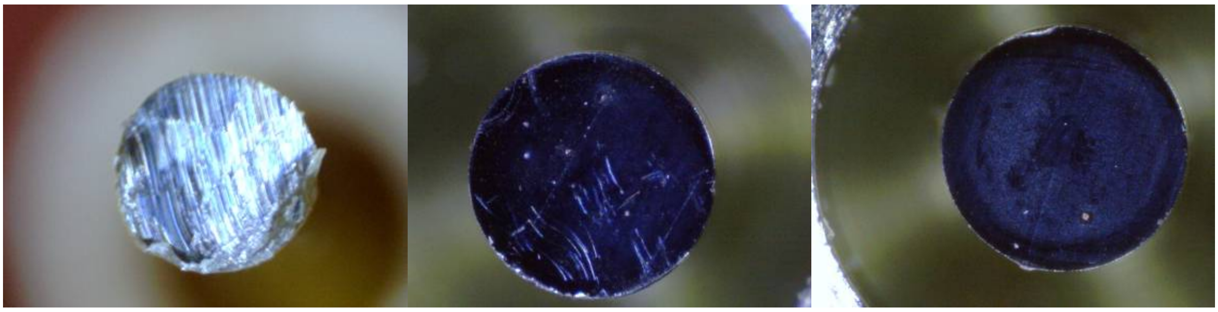

Figure 7: Unpolished (left), manually polished (middle) and machine polished (right)

An overview of all measured fibers and the transmission losses is presented in Table 2. The transmission results of hollow waveguides seem most promising in first instance. However, bending losses are substantial and make them less attractive. The transmission through the bandgap HWG is significantly lower compared to the other fibers and also suffers from bending losses. As they are designed specifically for CO_2 laser applications, the transmission at 6.45 μm will be even lower.

Therefore, the silver halide fiber seems most practical for clinical applications. These fibers have low bending losses and there is no risk of damaging the distal end due to occluding particles, which is a potential risk using hollow waveguides.

Table 2: Overview fiber transmission and attenuation at 10.6 μm.

Fiber type	Core diameter [μm]	Fiber length [mm]	Transmission [%]	Transmission loss [%/m]	Transmission loss [dB/m]
Hollow waveguide Polimicro	1000	550	97,3	-	-
	500	1000	73,6	23,1	1,14
		2000	50,5		
	320	800	63,3	34	1,80
		1400	42,9		
Silver halide fiber Ceramoptec	850	1000	69,7	15,2	0,72
		1500	62,1		
	600	1000	55,2	26,4	1,33
		1500	42		
Band-gap HWG Omniguide	500	1250	38,2	-	-

During the site visit at ISL, transmission measurements were performed at 6.45 µm with the silver halide fiber and the HWG. The pulse width of this system was ~30 ns and the energy around 4.5 mJ per pulse. This resulted in a transmission of ~50% for both the fiber and the HWG, as shown in Table 3.

Table 3: Comparison fiber transmission at 6.45 and 10.6 µm.

Fiber type	Wavelength [µm]	Core diameter [µm]	Fiber length [mm]	Transmission [%]
Hollow waveguide (Polimicro)	10.6	**500**	**1000**	73,6
	6.45			**50**
Siver halide fiber (Ceramoptec)	10.6	**850**		69,7
	6.45			**48**

5. Fiber damage threshold

The damage threshold of the solid core fibers to the high peak powers and short pulse lengths needed to be tested. The damage testing was performed using the OPO ns system. It proved that the damage threshold of the fiber was well above a fluence of 1 J/cm^2.

6. Clinical applicability

With the energies obtained with the ISL 6.45 µm OPO, the fluence of the beam coming out of this 850 µm diameter fiber is too low for adequate tissue ablation. A miniature lens has to be mounted at the fiber tip to focus the beam at the tissue to obtain a high enough fluence for efficient tissue ablation.

7. Conclusions

The target of this deliverable has been achieved. A fiber delivery system has been developed for the 6.45 µm OPO output to enable endoscopic tissue ablation.