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Silica Fibers with Enhanced UV Performance

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ABSTRACT

In developing a better understanding of the requirements on optical fibers to make them more useful for medical and other applications where UV light/lasers are the preferred source, previous papers have dealt with all silica optical fibers. Here we describe the UV transmission of all the available fiber types; illustrating, for commercially available fibers, the effects of fiber type, core diameter, cladding thickness and core OH level on this transmission. We also describe our first efforts to fabricate a new, modified hard plastic clad silica fiber with enhanced UV performance. Finally some of the remaining problems and concerns are identified and reviewed.

1. INTRODUCTION

Optical fibers for high power UV transmission have been under intensive development for the last several years[1-6]. With improvements in UV transmission properties, silica optical fibers should provide effective fiber delivery systems for many potential medical and industrial applications of high power UV lasers, where transmission of high peak and average intensities is needed for extended time durations. Commercially available OH-rich fibers , usually used for UV applications, behave well when working with relatively low repetition rates but their transmission degrades when subjected to high repetition rates as often employed with excimer lasers[3-7]. While the fall in transmission under 308 nm irradiation is seen only for long fiber sections and is normally recoverable after termination of exposure, at shorter laser wavelengths - such as 248 nm or 193 nm - catastrophic failure and only partially recoverable losses often occurs[3,5-7]. These losses appear to be due to laser-induced color centers. The mechanism of their formation in fibers has been treated in some recent investigations[7-9].

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In papers, presented in 1991[7,9], all silica optical fibers were prepared either by a rod-in-tube technique or totally by a plasma modified chemical vapor deposition (PMCVD) technique. The chemical compositions of the fibers were thus slightly different, but their OH levels varied broadly. All fibers displayed laser-induced absorption upon repeated irradiation with pulsed 266 nm light from the 4th harmonic of a Nd:YAG laser[7]. This absorption was centered at 265 nm. The nature of the defects responsible for the UV absorption in the fibers was probed by photoluminescence studies and the mechanisms of their photogeneration was discussed[9].

The main defect responsible for the laser-induced absorption at 265 nm was determined to be non-bridging oxygen hole centers (NBOHCs)[9,10]. In OH-rich fibers these gave rise to an unstable band at 265 nm, while in low-OH, oxygen-excess fibers these cause a more intensive, stable band at 265 nm. It has been postulated[9] that the NBOHCs in the latter fibers are produced by breaking the peroxy (O-O) bonds[11], that are found in oxygen rich fiber cores. For the OH-rich fibers several mechanisms can exist, including the dissociation of OH groups, which fit with the highly unstable defects observed. Studies have continued into the mechanisms of NBOHC formation in both types of all silica fibers. Results should become available later in 1992.

In this paper we will deal with the UV transmission behavior of types of fibers other than the all silica type, polymer clad optical fibers. There are two types of polymer clad optical fibers with pure silica cores. The original type is plastic clad silica fiber or PCS fiber. The cladding is a silicone polymer which is generally cured onto the fiber by thermal treatment. About 10 years ago the new type was invented[12]. Its name, hard plastic clad silica fiber or HPCS fiber, helps to distinguish it from the earlier type. Here the cladding is generally very thin ($<20\mu$), regardless of core size, and it usually is based on a UV-cured highly fluorinated acrylate. A number of advantages have been found for HPCS fibers in medical applications, both in sensing and laser delivery. Of particular note is the advantage they have in achieving an excellent combination of large core size, very high core/clad ratios, low microbend sensitivity, high initial strength and good failure resistance[13,14]. Worldwide there are several versions and suppliers of this fiber type.

Both types of polymer clad fibers have found extensive use in visible and near IR laser surgery systems, primarily due to the lower microbend sensitivity and the lower cost of the large core fibers employed in these systems. For many of these reasons as well as others, e.g. mentioned in references 13 and 14, there is interest in optimizing, especially, the HPCS type fiber for enhanced performance at the shorter wavelengths in the UV region. This is the reason we have begun the work reported below in conjunction with the more basic continuing studies on improving the UV behavior of the silica core in all silica optical fibers. After inspecting the behavior of commercially available fibers of each type, we describe preliminary results for a new improved version of HPCS for enhanced UV performance.

2. FIBER CHARACTERISTICS

In Table I the fiber characteristics of commercially available UV grade PCS fibers are summarized. Table II shows the characteristics of some additional PCS fibers, compared beside the 200μ core fiber from Table I.

TABLE I
PCS FIBER CHARACTERISTICS

Characteristic		PCS 200	PCS 600	PCS 1000
Core Diameter	μm	200	600	1000
Cladding Diameter	μm	380	750	1260
Jacket Diameter	μm	600	1060	1550
OH Content	ppm	˜300	˜300	˜300
NA [theoretical]		0.35	0.35	0.35
Loss at 0.85μm	dB/km	12	12	12

Silicone Resin Cladding, ETFE Jacket

TABLE II
PCS FIBER CHARACTERISTICS

Characteristic		PCS 200	PCS 200A	PCS 150
Core Diameter	μm	200	200	150
Cladding Diameter	μm	380	380	200
Jacket Diameter	μm	600	600	585
OH Content	ppm	˜300	˜50	˜300
NA [theoretical]		0.35	0.35	0.35
Loss at 0.85μm	dB/km	12	8	15

Silicone Resin Cladding, ETFE Jacket

Note that the PCS 200A is a low–OH core fiber and that the PCS 150 differs from the other high–OH fibers because its cladding is much thinner.

The analogous data on commercially available HPCS fibers is given in Table III. Again note that the cladding thickness for all is about the same, ˜15μ, which is 1/5 to 1/7 of that for the PCS fibers.

TABLE III
HPCS FIBER CHARACTERISTICS

Characteristic		HPCS 200	HPCS 600
Core Diameter	μm	200	600
Cladding Diameter	μm	230	630
Jacket Diameter	μm	500	1040
OH Content	ppm	~300	~300
NA [theoretical]		0.4	0.4
Loss at 0.85μm	dB/km	12	12

Hard Plastic Cladding, ETFE Jacket

The typical UV transmission data for all of these fibers is presented in the following section, where they are correlated with various fiber properties.

Lastly, we present the fiber characteristics of the experimental HPCS fiber that is being developed for enhanced UV performance. Table IV gives this data. The UV transmission for one of a recent set of fiber samples will also be compared in the next section with that of the appropriate HPCS fiber. For this first attempt a rather standard high–OH silica was used to test out some preliminary concepts. Better results are expected when a more optimized silica is employed for the core[15].

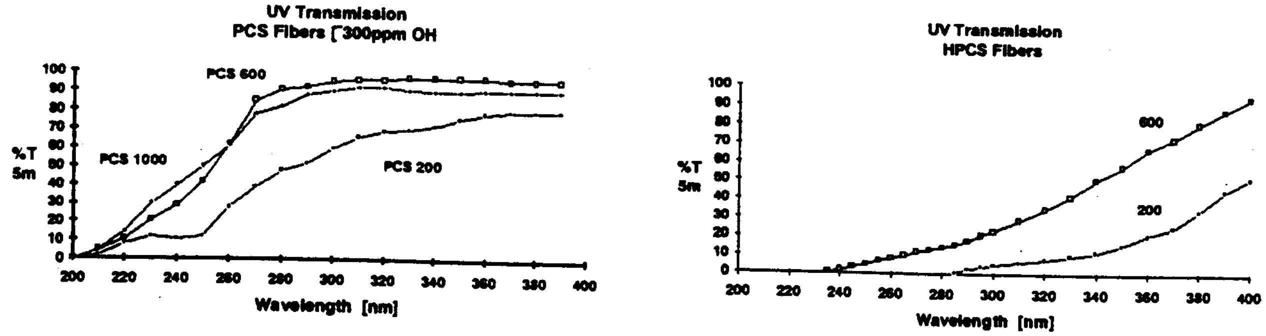
TABLE IV
EHPCS FIBER CHARACTERISTICS

Characteristic		EHPCS 200
Core Diameter	μm	210
Cladding Diameter	μm	230
Jacket Diameter	μm	300
OH Content	ppm	1200
NA [theoretical]		0.35
Loss at 0.85μm	dB/km	16

Experimental Hard Plastic Cladding, Nylon Jacket

3. UV TRANSMISSION VS. FIBER PROPERTIES

In the accompanying figures, we present the UV transmission of the various PCS and HPCS fibers by grouping them according to the following fiber parameters; fiber core size, core OH level, cladding thickness and fiber type. In all the figures the %T is given for 5 m long fibers. The data for the commercially available fibers are representative data, not necessarily from a specific fiber sample.



Figures 1a,b: The UV transmission of 5 m long samples of commercially available PCS fibers (a) and HPCS fibers (b).

Note that for each of the fiber types the smaller core diameter fibers, <˜500μ, have significantly poorer transmission capabilities. The available data for larger HPCS fibers is sketchy but does demonstrate similar behavior to that for PCS fibers, i.e. very difference in transmission between fibers with 1000μ cores versus with 600μ cores.

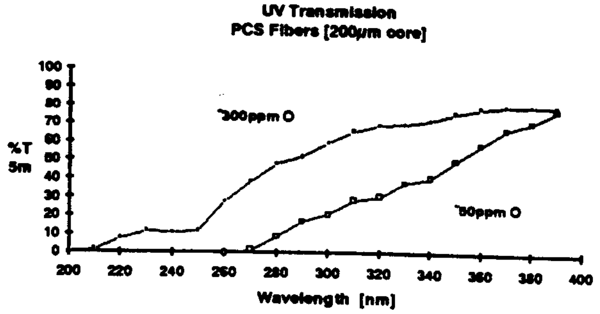


Figure 2: Effect of OH level in fiber core.

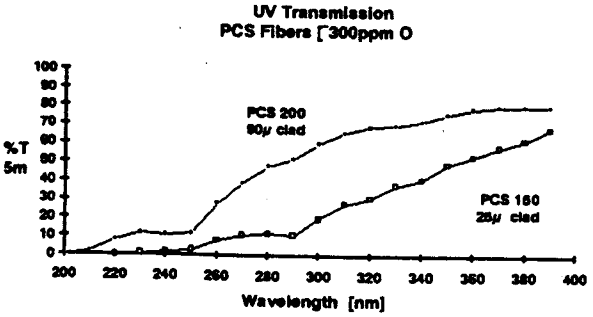


Figure 3: Effect of cladding thickness

These figures demonstrate that low OH content silica cores do not transmit UV light as well as medium to high OH content cores; and the PCS 150 appears to have much poorer UV transmission than the PCS 200 due to its much thinner cladding as well as its slightly smaller core diameter.

In the next three figures the effect of fiber type on UV transmission is illustrated. Figure 4 compares the UV transmission of PCS fiber with that of similarly sized all silica core fiber. Figure 5 compares the UV transmission of PCS fiber with that of HPCS fiber. Lastly, in Figure 6 the UV transmission of our experimental HPCS (EHPCS) is compared with that of the standard HPCS fiber.

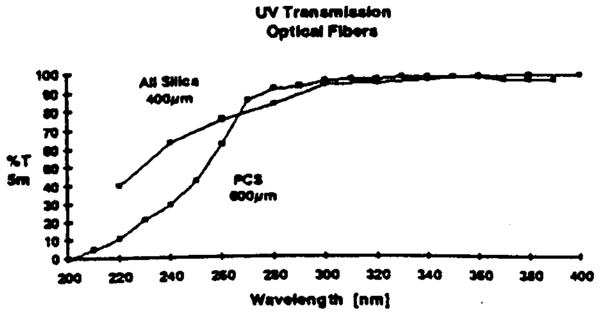


Figure 4. Fiber type comparison PCS/all–silica

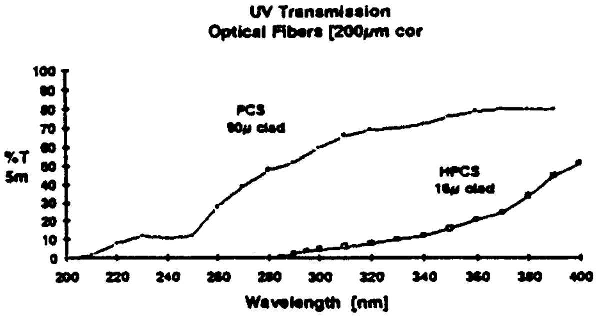


Figure 5. Fiber type comparison PCS/HPCS

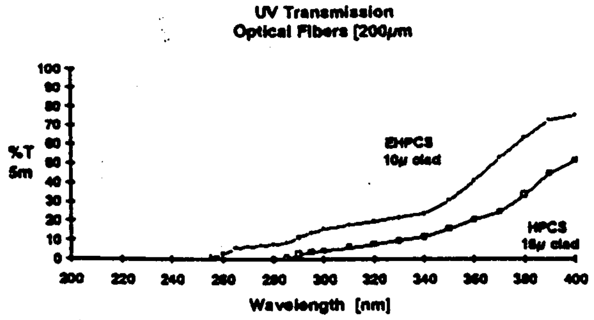


Figure 6. Fiber type comparison EHPCS/HPCS

Note that the PCS fiber transmits UV light as well as the all silica fiber down to the 270–280nm wavelength region, when similarly sized large core fibers are compared. The much thinner clad HPCS fiber transmits much poorer in the UV region than the PCS fiber. Finally the experimental HPCS seems to transmit better than the HPCS even though its cladding is even thinner than that of standard HPCS. Further comments and discussion follow in the next section.

4. DISCUSSION & COMMENTS

Reviewing the transmission data presented above the following trends and correlations appear to be evident. For a given fiber type smaller core diameters than about 400–500μ lead to larger losses and often higher cutoff wavelengths in the UV region. Above this core size the UV transmission is essentially the same within a fiber type. It is also observed that the transmission is reduced as the cladding thickness decreases, particularly at smaller core diameters. As the core diameter drops, especially below 200μ, significant signal travels at the core/cladding interface region and the spectral characteristics of the cladding material and the quality of the interface increasingly affect the transmission of light through the fiber. It might be said that the evanescent wave samples more of this region. In a similar manner as the cladding decreases in thickness, particularly for thinner core fibers, the energy travelling down the core can interact more with the buffer(primary) outer coating with decreasing transmission of light the consequence. It would thus seem that there may be a practical limit to how small a fiber core can be used to carry UV laser power for medical or other applications. Beyond the problems of coupling into fibers below ~400μ core size, it may be difficult to dissipate the energy lost within the fibers particularly for very high energy pulses and for moderately high continuous energy transmission in the UV spectral region.

As noted earlier the reduction of OH content in the core of the PCS fibers greatly reduces the UV transmission and increases the cutoff wavelength. This effect appears to behave similarly to that observed in the all silica fibers[3–7] and will not be further discussed here.

In comparing the UV transmission between different fiber types, as mentioned earlier the near UV transmission (>~280nm) of the large core PCS fibers is essentially equivalent to that of the all silica fibers. It is possible, however, that for very high energy densities, high pulse rates or long durations that they may have lower thresholds than the all silica fibers. This will have to be tested in the future.

The much lower performance of the HPCS fibers throughout the UV region not only is due to their thin claddings but also is due to the presence of UV absorbing photoinitiators used to cure them during the fiber fabrication process. This will be a potentially inherent problem for these fibers since the commonly used photoinitiators have significant extinction coefficients even as high as 370nm. In the deep UV region (≤280nm) their extinction coefficients are often 6 orders of magnitude higher than that of silica and even 3–4 orders of magnitude higher than the other components of the cladding. For larger core fibers this feature is diminished, especially if the laser input is localized to the inner 50% of the fiber's core area.

The preliminary results with the new experimental fiber EHPCS are most promising. Using standard high OH silica for the core, the new variation of HPCS shows significant improvement over the standard HPCS fiber and compares favorably to the thinner clad PCS 150 fiber. It obviously still needs further development and optimization to measure up to the UV behavior of comparably sized PCS fibers or all silica fibers. It will also be interesting to see how larger core fibers with this proprietary coating/process measure up to the other fibers. These will be the goals of the ongoing research and development of these fibers: to maintain the benefits of the hard thin clad fibers for medical and other applications while achieving UV transmission behavior at least comparable with the UV grade PCS fibers and hopefully also for all silica fibers.

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