Hard Plastic Clad Silica Fibers for Near UV Applications

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ABSTRACT

Many medical applications have been developed using light sources not only in the visible and near infra-red (NIR) regions, but also in the near ultraviolet (near UV) region of the spectrum. Hard Plastic Clad Silica (HPCS) have found much use in medical applications in general, but generally HPCS fibers are not recommended below 400 nm. Here we will describe HPCS fibers with excellent mechanical reliability and with optical losses of only 1.5 dB/m at 275 nm and less than about 0.2 dB/m at 350 nm. How this combination of properties can benefit diagnostic and surgical applications in the near UV will also be discussed.

1. INTRODUCTION

A number of the properties of HPCS fibers make them very desirable for medical applications, both for laser surgery and for in-Vivo sensing/endoscopy. High core/clad ratios, low loss, small/large core sizes and broad transmission window are of value for different reasons in each of the application areas. Numerous papers, primarily by Ensign-Bickford and by 3M at earlier SPIE meetings, have presented and discussed how the different properties are important in various medical applications[1-10].

However, as with all things, there have also been limitations to previously available products. In laser surgery applications there are two primary limitations. At very high laser powers, the cladding will vaporize, particularly near the fiber ends. This limitation is due to the thermal stability of the proprietary cladding materials, to the planarity of the end face, and to minor misalignment of the laser/fiber interface. The ultimate limiting factor is the first one, as improvements will eventually limited to the material thermal properties. The use of lasers operating at wavelengths below 400 nm, the near uv region, had been hampered by the fact that most hard claddings generally absorb light strongly in this region of the spectrum. Current results will show improvements in recent years, especially the latter problem.

In the biosensing/endoscopic applications, there are three areas where limitations become evident. A large NA is advantageous for these applications, however, in the past, for the higher NA HPCS fibers, the hardness, wear resistance and overall robustness were typically reduced from that of the "standard" NA product, making these fibers more susceptible to damage from handling. Developments in improving these aspects were recently reported[11].

In this paper we shall mention newer products, which address especially expanding the spectral range into the near UV region. Spectral and strength/reliability results are presented below showing the latest information on HPCS fibers from our company's Optran[12] fiber optic line.

2. EXPERIMENTAL

The UV, VIS and NIR spectral losses of high-OH Hard Plastic Clad Silica (HPCS) fibers were measured. A "cutback" method was employed using a Monolight Optical Spectrum Analyzer (OSA), manufactured by Macam Photometric Ltd of Livington, Scotland. The system includes a scanning monochromator, a 3-channel controller, a power supply, two light sources (deuterium and tungsten), and input and output blocks to handle fiber from 70 µm to 1000 µm in diameter.

The "cutback" method consisted of using two pieces of same-type and draw fiber with a length ratio of 1:4-5. The longer lengths were measured via a Tektronix ODTR, and the shorter lengths were manually calculated (i.e. the number of loops were counted and multiplied by Π times the diameter of the spool.) The "cutback" length (in meters) was calculated by subtracting the shorter length from the longer length of fiber. More complete details on the spectral measurements were reported earlier[13].

The numerical apertures for the different fibers in this study were made using a set up which involved taking diameter measurements of the projections onto a black surface shielded from direct ambient light at five different distances from the fiber end. A white light source was over-launched and overfilled into the input end of the fiber. Meter long samples were used with about a 180 degree angle bend relative to the output end. The bend radius was on the order of a 40-50 cm. The ends were secured to metal blocks to guarantee stability of placement during testing and to improve reproducibility. NAs calculated at the five distances were averaged to yield the reported NA.

The mechanical property primarily reported is the dynamic strength as measured by a universal testing machine and plotted on a Weibull plot. Gauge length was 1 meter. The fiber is stretched while horizontal and anchored at the two ends by wrapping several loops around a tapped mandrel of approximately 10 cm diameter. About 1.7 meters of fiber is consumed per trial. Results presented below are generally from one or two fibers where 15-20 samples are taken from a specific fiber run. Tests were made at ambient temperature and relative humidity. Temperatures ranged in the 20-27 C, and relative humidity [RH] primarily was 30% $\pm$ 7%, although some samples were tested with RH as high as 75-80%. Strength data are plotted according to the generally accepted Weibull approach.

3. RESULTS

Figure 1 shows the typical spectral loss of our standard, high-OH HPCS (HUV) fiber with core/clad glass geometries of 600µm/630µm and a numerical aperture (NA) of 0.37 from the wavelengths 300 nm to 1200 nm. This fiber has pure undoped silica as the core material and hard plastic cladding with an over jacket of. Tefzel, a DuPont extrudable fluoroplastic product..

Figure 2 expands the UV spectral response to better illustrate the viability of the new HUV HPCS to transmit light down to at least 275 nm within the near UV region.

UV, VIS, IR SPECTRUM (CUTBACK 80 M)
HUV 600/630//950 T
2000

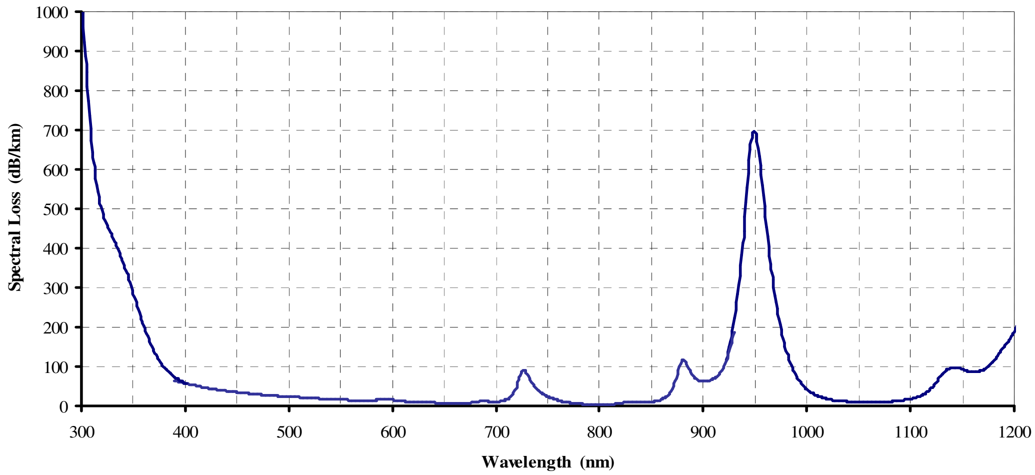

Figure 1: Full spectrum (UV, VIS, NIR) high-OH fiber, NA = 0.37

UV SPECTRUM (CUTBACK 80 M)
HUV 600/630//950 T
2000

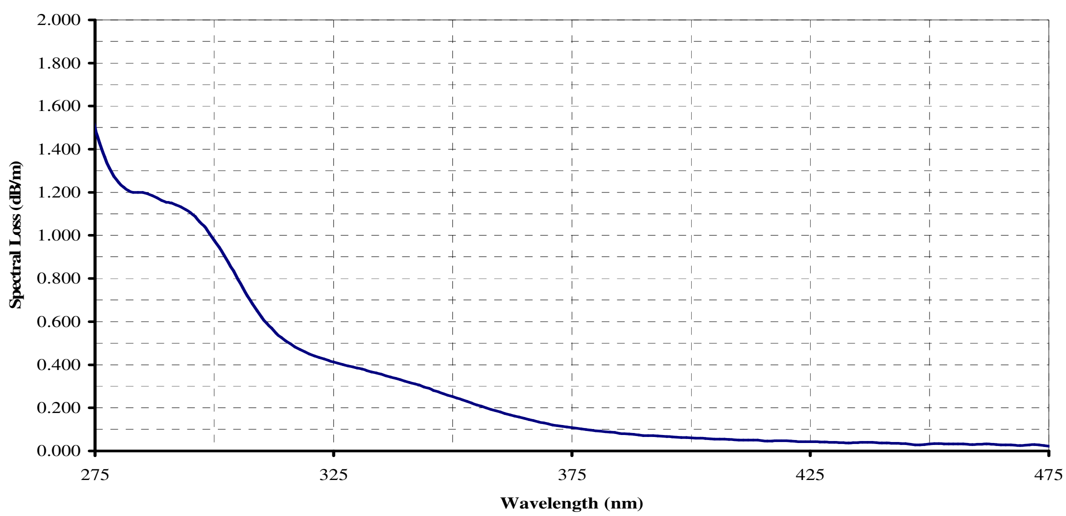

Figure 2: Expanded spectrum for NUV region from Figure 1

As a measure of the reliability of these fibers, we present dynamic strengths measurements for fibers make over a 5 year period and including a fiber tested and retested during this period.

Figure 3 presents the data for samples of standard Optran[2] HPCS fiber produced in 2004 and tested in 2004. Fiber dimensions are given in the chart title. Note that log S = 2.85 is a strength of 4.88 GPa and log S = 2.90 is a strength of 5.48 GPa.

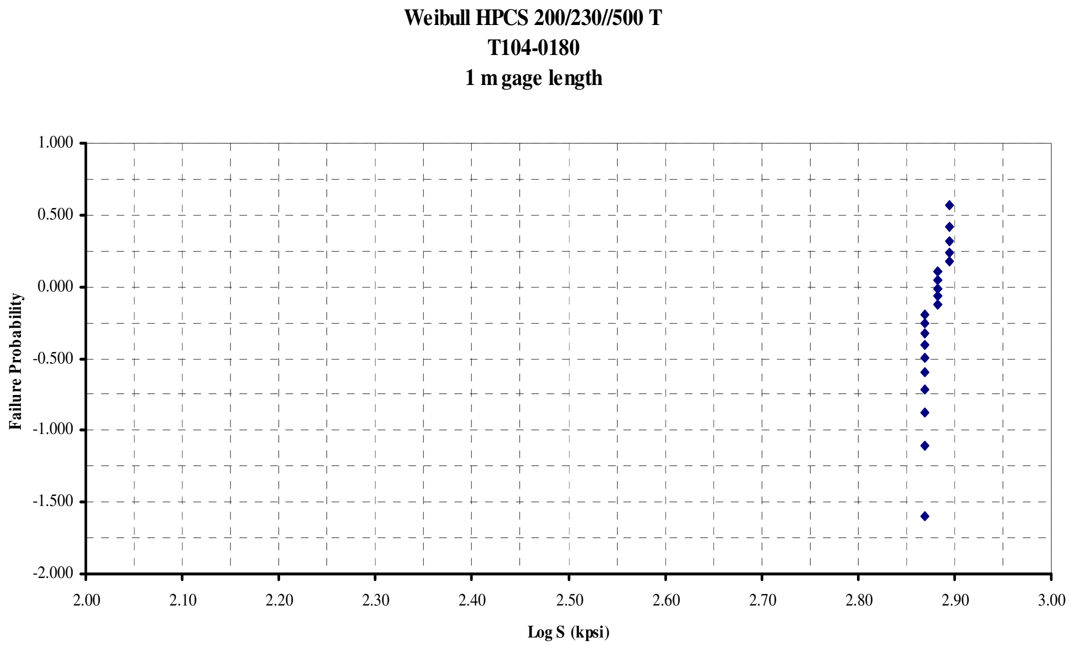

Figure 3: Weibull Plot of dynamic strength of Optran HPCS fiber

In Figure 4 the Weibull plot compares fibers drawn in 1999 [left points black], and in 2004 [right points, shaded] Note that log S = 2.80 is a strength of 4.35 GPa.

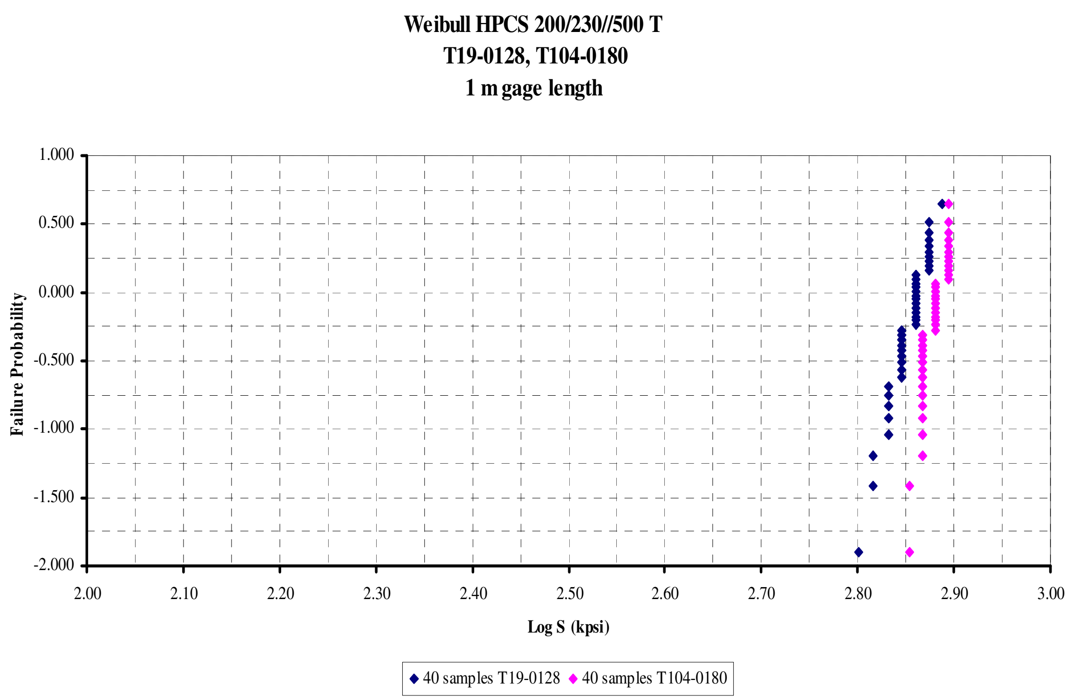

Figure 4: Weibull Plot of Optran HPCS fiber; drawn ‘99[left], drawn ‘04[right]

In Figure 5, the Weibull plot compares strength for a fiber drawn in 1999, tested in 2000 [circles] and again in 2004 [shaded triangles] after storage in varying humidity (10-80% RH) on spools under about 0.1 GPa (15 kpsi).

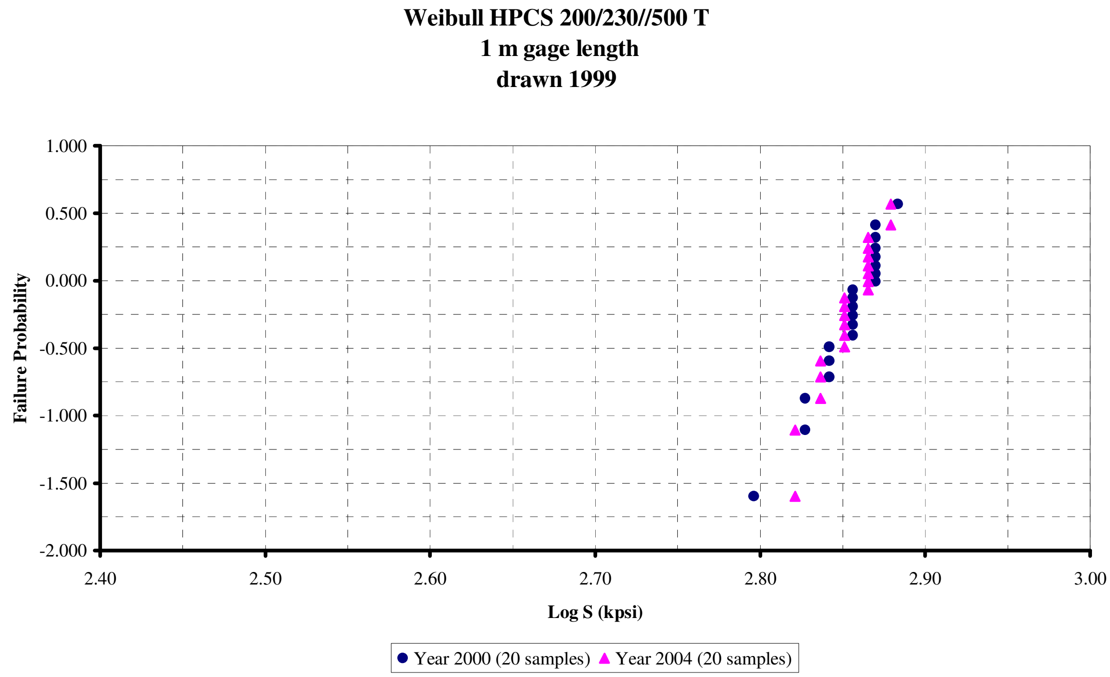

Figure 5: Weibull Plot of Optran HPCS fiber; test '00[circle], test '04[triangle]

Also critical for most medical applications is that the optical fiber be classified for biocompatibility. The best standard is a Class VI rating.

Table I

Class VI Classification Test Results
Test Article: Hard Polymer Clad Silica Optical Fiber

ACUTE SYSTEMIC TOXICITY (USP): Test article extracts in saline, alcohol in saline, polyethylene glycol 400 and cottonseed oil did not produce a significantly greater systemic reaction than the blank extractant when injected into mice.
INTRACUTANEOUS TOXICITY (USP): Test article extracts in saline, alcohol in saline, polyethylene glycol 400 and cottonseed oil did not produce a significantly greater tissue reaction than the blank extractant when injected intracutaneously into rabbits.
IMPLANTATION TEST (USP): Implantation of the test article into rabbit muscle for 7 days did not produce a significantly greater macroscopic tissue reaction when compared to the USP negative control plastic.
The sample of test article extracted at a ratio of 60 cm2 /20 ml and at a temperature of 121°C for 1 hour, met the requirements of a USP Class VI Plastic.

4. DISCUSSION

As mentioned earlier, the high core/clad ratios, low loss, range of core sizes and broad transmission window of HPCS fibers are of value for different reasons in each of the application areas. The advantages are summarized in Table II for the common advantages.

Table II

Advantages of HPCS Fibers for All Medical Applications

High Inherent Strength and Good Fatigue Behavior	Tighter Bends Permitted in Use and Packaging & Storage Easier
Hard, Thin, Adherent Cladding	Apply Connectors Directly Over Clad Fiber; Improved Reliability
Crimp & Cleave Connectors on Proximal End	Potentially Less Expensive, High Volume, Disposable Devices
Cladding Non-Thrombogenic	Diminished Danger in Long Operations
Low Bioload Materials	Easier to Sterilize & to Keep Sterile

As this table shows there are many good reasons for choosing HPCS optical fibers for use in medical devices. The use of lasers operating at wavelengths below 400 nm, the near uv region, had been hampered, in the past, by the fact that most hard claddings generally absorb light strongly in this region of the spectrum. The current results show significant gains over earlier HPCS products.

The spectral transmission of HPCS, Optran HUV, fibers extends nicely into the near UV region. Typically, attenuations of <1 dB/m are observed down to 300 nm, with values of 0.2-0.3 dB/m at 350 nm. Even down at 275 nm, the attenuation is only about 1.5 dB/m. With some care high pulse power, as well as cw power can be transmitted through them.

In summary, we have also shown that HPCS fibers are robust with dynamic strength comparable to all silica fibers. Weibull mean strengths are above 4.2 GPa [>600 kpsi] with very sharp/steep slopes meaning a tight distribution of flaws. Here we also reported that storage for up to 5 years at about 0.1 GPa [15 kpsi] does not affect the strength nor the distribution of laws for these fibers.

In short, combined with their cost benefits and handling advantages, they should be investigated for all medical applications, especially disposable ones.

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