Bulk solid-state laser amplifiers with "tailored" gain spectra

JGMA plans to develop versions of our patented VHGM amplifier having "tailored" gain spectra. In this design, the two lateral highly reflecting (HR) surfaces of the VHGM slab that establish the seed beam's zig-zag beam path in the slab are coated to have different center wavelengths so they only partially overlap over a desired wavelength range.

Fig. 1 shows one situation where 100 nm-wide HR bands overlap over a nominal 50 nm range, and another situation where the HR bands overlap over a 10 nm range. The thin-film coatings can be designed to give any desired overlap range down to some minimum controllable overlap determined by the coating technology being used, the coating materials and design, the laser material, and other factors.

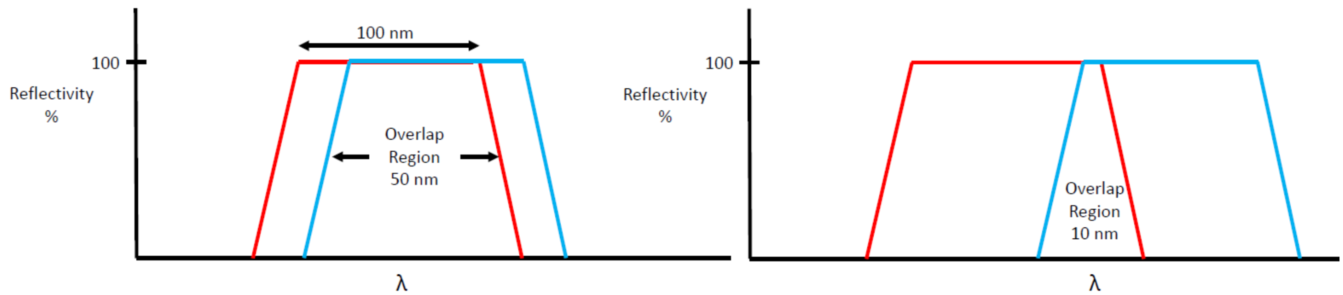


Figure 1 HR coating overlap, Side 1 coating = red, Side 2 coating = blue

In the VHGM amplifier design, only wavelengths that fall in the spectral overlap region of the two coatings can make multiple zig-zag bounces through the slab as needed to achieve a long gain length and high gain. Fig. 2 shows how the spectral overlap region of the two coatings might overlap the gain spectrum of an Yb-doped or other broad-gain-bandwidth laser material. Wavelengths that fall within gain spectrum, and at the same time within the spectral overlap region of the two HR coatings, determine the effective gain spectrum of the VHGM amplifier slab.

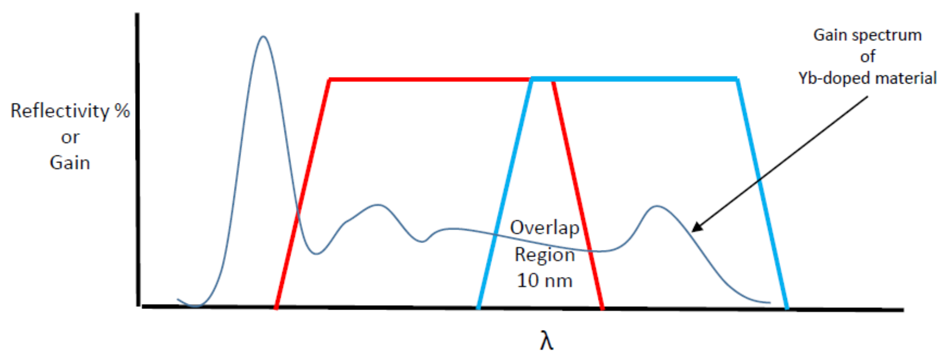


Figure 2 Effective gain bandwidth determined by spectral overlap of HR coatings.

Such "tailoring" can be implemented according to needs of specific laser amplifier design situations. This cannot be done in an optical fiber amplifier (which relies on total internal reflection to guide the seed beam in the fiber), nor in bulk-solid-state amplifiers where the seed beam passes straight through the gain medium, and not in other bulk amplifier designs that rely on TIR to configure a zig-zag beam path.

The filtering action of the VHGM HR coatings is expected to prevent parasitic ASE build-up at wavelengths outside the intended gain spectrum even when the main peaks of the Yb-doped gain spectrum are well away from the desired gain region. The VHGM design can compensate for reduced per-cm gain when operating away from gain peaks by virtue of the long gain lengths achievable in VHGM slabs. Other possible applications of gain-tailored VHGM amplifiers include reduction of ASE power that competes directly with the seed (by reducing the bandwidth that contributes to ASE at the seed wavelength), amplifiers with flattened gain curves (by isolating and working in a flat portion of the laser medium's gain curve), *e.g*, as needed to reduce gain narrowing, and ASE sources with controllable center wavelengths and emission bandwidths.

The strategies described above, along with our tailored-bandwidth amplifier, enable use of many different types of Yb-doped gain materials in our system. Many materials have usefully large emission cross-sections over a wide wavelength range and good thermal conductivity suitable for achieving good beam quality at 10 to 100W average power levels, and higher. Candidates include Yb-doped garnets, vanadates, fluorides, tungstates, double tungstates, borates, apatites, sesquioxides, oxyorthosilicates, and CALGO. Ceramic materials may also be used. Tailored-gain amplifiers that employ Ho-, Tm-, or Er-doped materials are also feasible due to the long gain lengths achievable in VHGM slabs.

As examples, Fig. 3 shows room-temperature emission cross-sections for Yb:YAG, Yb:YLF, Yb:CaF_2, and Yb:SrF_2. Fig. 4 shows corresponding room-temperature quasi-three-level net gain curves. (The β parameter refers to inversion fractions determined by how hard the gain medium is being pumped).

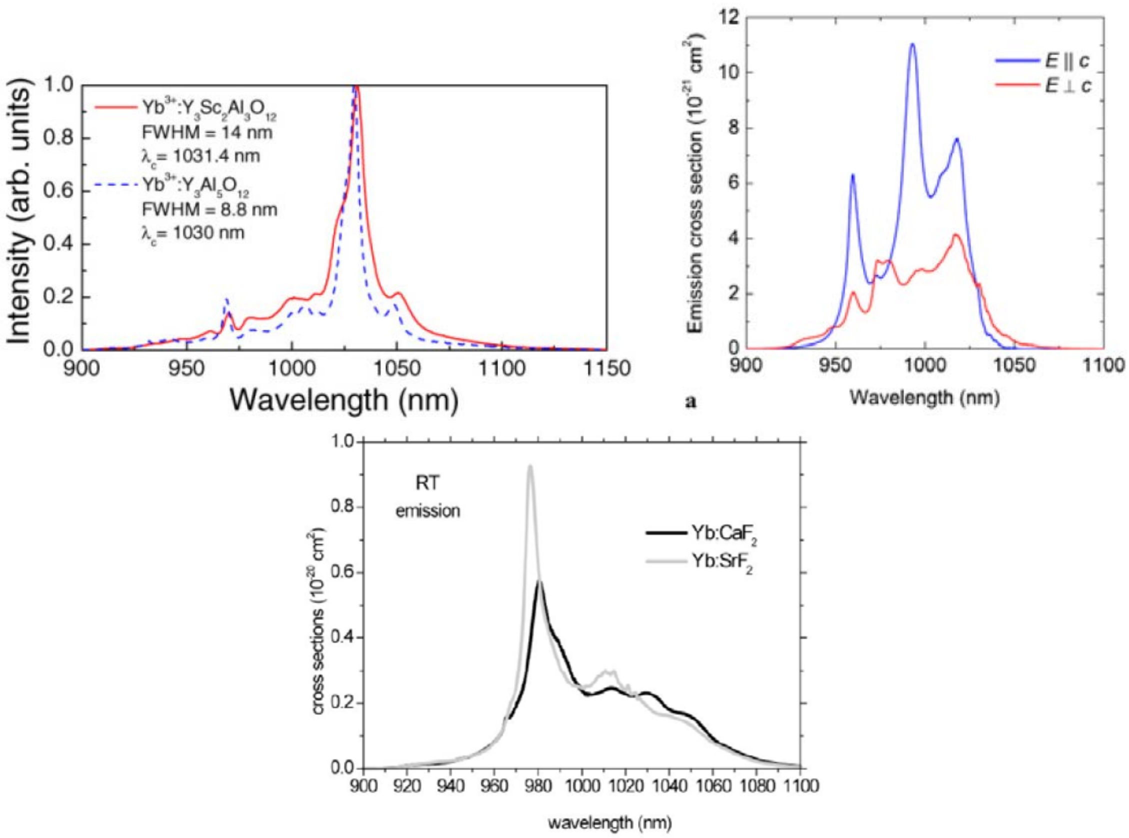
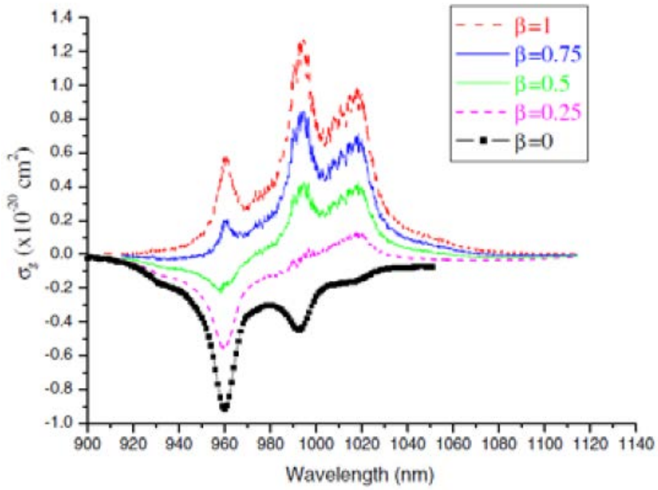


Figure 3 Emission cross-sections for Yb:YAG (top left), Yb:YLF (top right), YbCaF_2, and Yb:SrF_2 (bottom)



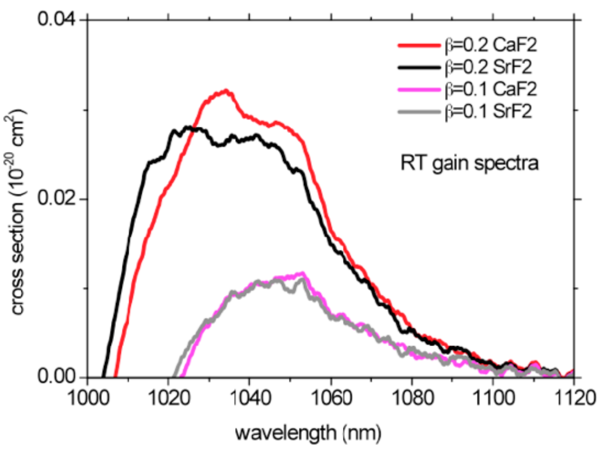


Figure 4 Quasi-3-level net gain cross-sections for Yb:YLF (top) and Yb:CaF_2 (bottom)

Net gain coefficients for quasi-3-level materials are calculated using:

Eq. 1 $$g_{o,net}(\lambda) \quad = \quad N_T\,[\,p\sigma_{eff,em}(\lambda)-(1-p)\sigma_{eff,abs}(\lambda)]$$

where $g_{o,net}$ is the net gain coefficient (cm^{-1}) at the laser or extraction wavelength λ, N_T is the total doping-ion concentration per unit volume, p is the inversion fraction in the upper laser manifold (N_{upper}/N_T, all ions are assumed to be in either the upper- or ground-state manifold), $\sigma_{eff,em}$ is the effective emission cross-section at the extraction wavelength, and $\sigma_{eff,abs}$ is the effective absorption coefficient at the laser/extraction wavelength. Gain curves are generated by digitizing the absorption and emission spectra, or, alternatively, by digitizing the measured absorption (emission) spectrum and then calculating the emission (absorption) cross-section using the reciprocity method. One can then apply Eq. 1 to arrive at the net gain coefficient as a function of wavelength, with p or as a parameter (or β in Fig. 4).