important advantage for the practical applications is the lifespan extension of such composites. In an ambient test with an excitation power at two times above the thresholds, the lifespan of neat films is only in the order of $10^4$ shots while that of the blend films can reach $10^6$ shots, comparable to the single-photon pumped polymer lasers [33].

## 4. Conclusions

In conclusion, we have introduced ET-coupled dye-polymer composite materials as a promising candidate for TP-pumped laser applications. Time-integrated and time-resolved spectroscopic studies have been carried out to investigate the emission properties of the hybrid composites and the underlying mechanisms. Compared with neat polymer films, frequency up-converted gain-induced ASE has been observed in blend films with significantly-reduced thresholds. The ASE decay lifetime, dependent on the excitation power, is found to be in the order of 10 ps. We have also demonstrated a low threshold TP-pumped DFB laser, with over 100 times of lifespan extension. The excitation threshold is orders of magnitude lower as compared with previously characterized semiconductor nanocrystals [11,12,17], nanodisks [13], and nanowires [10], and the current system is among the lowest in TP-pumped polymer lasers to the best of our knowledge [7–9]. Such composite gain materials can be used as an alternative method to circumvent the two major drawbacks in traditional TP-pumped systems, i.e. high threshold and short lifespan, with potential to push forward the practical applications of frequency up-converted lasers. Similar to other polymeric gain medium, the composites can be incorporated to various resonators to form different types of micro/nano-lasers [34,35]. The required pumping wavelength and threshold power are readily available in today's commercial lasers for multi-photon microscopy, so the composites introduced here can be implanted as laser sources for light-activated therapeutics studies. The ET pumping idea is generally valid, and one can choose the functionalized donors or acceptors to develop up-converted laser sensors [36,37]. These implications can be done in vivo since the NIR pumping sources can penetrate deeply inside the tissue. Still, more interesting applications of such up-converted lasers can be envisioned as new polymeric composite materials are further developed for using as efficient TP-pumped gain materials.

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