RANDOM LASERS

Playing pinball with light

Without a well-defined cavity, there is no obvious way to control the resonant modes in a random laser. Experiments now show that shaping the optical pump allows for controlled single-mode operation at predetermined lasing wavelengths.

Stefan Rotter

Remember pinball machines — countless hours spent trying to keep a steel ball bouncing around? Random lasers[1] are a little like those machines (pictured), with the aim being to keep light inside a disordered gain medium for long enough to provide a level of feedback sufficient for reaching the lasing threshold. Unlike the arcade game, however, researchers don't have easy access to 'flippers' to keep the light in play. Writing in *Nature Physics*, Nicolas Bachelard and colleagues[2] present an innovative solution to this problem. Their approach is to manipulate the scattering system by tuning the profile of the beam used for optical pumping — tweaking the pinball machine from inside.

To understand why this work represents an important step forward, it is best to recall the fundamental problem that random lasers face: they lack a well-defined cavity to trap the light. This means that they typically emit light at multiple frequencies, as many resonant modes reach the lasing threshold for similar values of the applied optical pump. Most applications, however, require a well-resolved single-colour laser beam, like that provided by more conventional laser sources. The angular emission patterns of random lasers are also typically messy, with light radiated outwards in almost every direction.

How to address this issue is a vexing question. The first ideas focused on engineering the underlying gain medium, which required, for example, sophisticated techniques to produce structures made from monodisperse microspheres[3]. In this scenario, the resonance frequencies of the medium can be adjusted by choosing the appropriate microsphere size. Alternative solutions include engineering the absorption of the medium[4] or embedding liquid-crystal droplets in a disordered material to create a system amenable to external tuning both with an applied electric field and by modifying the temperature[3]. Although these ideas have provided important advances, their flexibility is limited and restricted in terms of the lasing properties that they can control.


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The approach implemented by Bachelard *et al.*[2,5] has the potential to overcome these limitations. Their strategy builds on recent developments in the emerging field of wavefront shaping[6], which offers the possibility of creating almost arbitrarily complex light fields with the help of a digital 'spatial light modulator'. Using such a device to shape the optical pump beam, which provides the energy for their random laser, the team managed to gain access to the inner workings of the light-scattering process in the underlying random medium. By creating a feedback loop between the emitted frequency spectrum and the spatial light modulator, they optimized the pump profile to suppress all but one of the lasing modes, achieving controllable single-mode operation at a predetermined emission wavelength.

Although shaping the pump profile of random lasers was attempted in earlier experiments[7,8,9], it is the fully automated control of the feedback through the many degrees of freedom in the spatial pump profile that makes this approach very efficient. The flexibility of this technique is particularly promising — it could, in principle, also be used to achieve mode locking in random lasers[9], a directional emission profile[10] or temporal control over the lasing modes[11]. Because Bachelard *et al.*[2] already chose to study the challenging case of a weakly scattering random laser, where lasing modes overlap both spatially and spectrally, their technique may be directly transferable to less demanding types of random or conventional lasers.

In particular, as the proposed pump optimization could essentially be employed on any optically pumped laser, it also has great potential for practical applications. The big advantage of such a feedback control compared with more conventional control techniques would be its potential flexibility to adjust different kinds of laser deficiency with minimal temporal delay. The scope of such a control scheme could range from correcting a small temperature-induced frequency shift to governing beam filamentation in high-power lasers. An exploration of these topics may lead to several useful insights.

On the other hand, the results presented by Bachelard *et al.*[2] also pose interesting theoretical challenges. As their optimization algorithm works like a black box that completes its task without providing much physical insight, several obvious questions are raised: how does an optimized pump profile manage to favour a selected mode over all other possible modes? What is the global maximum that can be reached by such an optimization procedure and what conditions are fulfilled at this maximum? Could we even learn something about the spatial dielectric profile of a random medium through the effect that certain pump profiles have on its emission spectrum? Experts in inverse-scattering problems may have a lot of answers to contribute to such questions.

In summary, the work by Bachelard *et al.*[2] adds a number of new control buttons to random lasers, bringing us an important step closer to the goal of making these exotic light sources externally tunable.

One could also say that the team's novel approach sets a new record score for 'pinball with light' and makes this an attractive, more challenging game to play in the future. ❐

Stefan Rotter is at the Institute for Theoretical Physics at Vienna University of Technology, Wiedner Hauptstraße 8-10/136, 1040 Vienna, Austria.
e-mail: stefan.rotter@tuwien.ac.at

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