

Flashlamp-Pumped Laser Dyes: A Literature Survey

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Citation: [Applied Physics Letters](#) **19**, 345 (1971); doi: 10.1063/1.1653946

View online: <http://dx.doi.org/10.1063/1.1653946>

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T_c is the nematic-isotropic transition temperature. Both theory and experiment show a weak temperature dependence for γ over the entire nematic range.

As an illustration of the application of the two-frequency addressing scheme, we may consider the sequential addressing of a multicharacter numeric display in which there are, associated with each character, an eight-segment front electrode and a single continuous back electrode [Fig. 2(a)]. The back electrodes are sequentially addressed by a train of, say, rectangular pulses $V_{x,i}$ of sufficient pulsewidth as to constitute the "low-frequency" signal which renders dynamic scattering. Data are presented to the segmented electrodes of each character in the form of modulated high-frequency (dielectric alignment) signals $V_{y,j}$ whose temporal coincidence with the sequential low-frequency pulses is synchronized so as to render clear those character elements which are not intended to "frost". An example of such synchronized waveforms is shown in Fig. 2(b), assuming a twelve-character display¹⁰ ($i = 1, 12$) of eight-element characters ($j = 1, 8$). This addressing scheme is also applicable to topologically equivalent arrays, such as multielement matrix displays.

We thank J. E. Bigelow for helpful discussions and S. Aftergut, H. S. Cole, and G. J. Sewell for the formulation of appropriate experimental materials. D. F. Hege and R. J. Winne provided technical assistance.

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⁵A nematic parallel-plate capacitor with semitransparent electrodes; MBBA denotes *p*-methoxybenzylidene-*p*-*n*-butyl-aniline.

⁶The details of this calculation will be published elsewhere.

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¹⁰The number of characters which can be addressed without replication of circuitry is limited by duty-cycle considerations which are dictated by the decay time of the scattering.

APPLIED PHYSICS LETTERS

VOLUME 19, NUMBER 9

1 NOVEMBER 1971

Flashlamp-Pumped Laser Dyes: A Literature Survey

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Fifty-nine flashlamp-pumped laser dyes are tabulated with their literature references. Lasing wavelengths and appropriate solvents are given for each dye.

The recent emergence of the flashlamp-pumped organic dye laser as a tunable source of intense coherent visible radiation is of considerable significance for researchers in the fields of photobiology, photochemistry, and photophysics. The rapid proliferation of commercially available dye lasers in the last year is indicative of the popularity possessed by this new member of the laser family. Although the theory and instrumentation of the flashlamp-excited organic dye laser is the subject of several reviews,¹⁻³ there exists no recent catalog of dyes which have been lased in these systems. The idea for this survey was conceived during a routine search for lasing dyes which could be used in our study of the primary processes in plant photosynthesis.

Although a very large number of dyes have been lased under giant-pulse or nitrogen-laser stimulation, the number of dyes which lase with flashlamp

excitation is somewhat smaller. The longer excitation pulse of the flashlamp (500 nsec to a few microseconds), as compared to the Q-switched laser's pulse of 10–30 nsec, tends to magnify the effects of intersystem crossing to the triplet state. Thus, the possibility of triplet-triplet absorption reducing the gain of the dye becomes increasingly important with a longer exciting flash duration. Hence dyes which lase effectively under flashlamp conditions are usually compounds with low intersystem crossing rates. Recently the addition of triplet-state quenchers (TSQ) has proven effective in lengthening the laser pulse and lowering the threshold in some dye systems.^{4,5} Judicious selection of appropriate TSQ additives may extend the number of dyes available for flashlamp-pumped lasers.

Although a significant number of dyes which lase under flashlamp stimulation belong to either the

xanthene, acridine, or coumarin families, structural considerations in dye selections have generally been ignored.^{1,6} Furumoto and Cecon have indicated that lasing dyes generally possess heterocyclic rings or separated phenyl ring systems. Hence they conclude that a mild localizing perturbation to the excited delocalized π system, generated by a heteroatom or single bond, is necessary to prevent rapid intersystem crossing.⁶

A listing of all published flashlamp-pumped dyes with their references is given in Table I. The lasing wavelength range as well as the lasing maximum wavelength are indicated as reported in the original source. It should be noted that not all dyes listed will lase efficiently in every flashlamp-pumped dye laser. For example, since intersystem crossing appears to occur quite rapidly in dyes lasing in the uv region,

these lasers require a high-power flashlamp with a rise time shorter than 100 nsec. In addition, these dyes must be used with a specially designed liquid cell, due to their inherent high molar absorptivities.⁶ Since fluorescence quantum yields are sensitive to the local environment of the excited molecule, the lasing efficiencies of the tabulated dyes depend on the solvent used. For this reason the dye solvents are also listed. Thus, because of the sensitivity of the dye emission to experimental operating conditions, it is advisable to consult the original reference before attempting to lase any of the tabulated dyes.

The authors wish to thank J. Bunkenburg and C. Leung for their encouragement, and J. R. Bolton for his helpful advice and support.

TABLE I. Summary of flashlamp-pumped laser dyes reported in the literature.

Dye	Solvent	λ_{nm}	λ_{max}	Ref.
1 <i>p</i> -terphenyl	DMF	...	341	a
	dioxane	342.5–355.5	...	a
2 2,5-diphenyl-1,3,4-oxadiazole (PPD)	dioxane	...	348	a
3 isopropyl-2-phenyl-5(4-biphenyl)-1,3,4-oxadiazole	cyclohexane	...	361	a
	EtOH	...	369.8	a
4 2-phenyl-5(4-biphenyl)-1,3,4-oxadiazole (PBD)	EtOH	...	362.5	a
5 2,5-diphenylfuran (PPF)	DMF	...	371	a
	dioxane	...	371	a
6 <i>p</i> -quaterphenyl	DMF	...	374	a
7 2,5-diphenyl-oxazole (PPO)	dioxane	...	381	a
8 2(1-naphthyl)-5-phenyl-oxazole (α NPO)	EtOH	...	400	a
9 <i>p,p'</i> -diphenylstilbene	benzene	...	409	a
	DMF	...	409	a
10 2,5-dibiphenylloxazole (BBO)	benzene	...	410	a
11 2-hydroxy-4-methyl-7-amino-quinoline	EtOH	...	413	b
12 <i>p</i> -bis[2-(5-phenylloxazolyl)]-benzene (POPOP)	toluene	...	419	c
13 aquafluor (PPO + POPOP)	EtOH	...	420	c
14 liquifluor (PPO + POPOP)	EtOH	...	422	c
15 <i>p</i> -bis(<i>o</i> -methylstyryl)-benzene (bis MSB)	toluene	...	424	c
16 2-hydroxy-4-methyl-N-dimethyl-7-amino-quinoline	EtOH	...	425	b
17 acridone	EtOH	...	435	c
18 2,5-bis[tert-butylbenzoxazolyl(2)] thiopene (BBOT)	benzene	...	437	a
19 7-methylamino-4,6-dimethylcoumarin	EtOH	430–450	443	b
20 7-ethylamino-4,6-dimethylcoumarin	EtOH	430–450	446	b
21 4-methylumbelliferone	H ₂ O(pH ~ 9)	450–470	...	d
	H ₂ O(pH > 9)	...	454	e
	H ₂ O	...	457	f
	H ₂ O	...	454	g
	H ₂ O	...	454	h
22 7-hydroxycoumarin	H ₂ O(pH ~ 9)	450–470	...	d
	H ₂ O(pH = 9)	...	459	i
	H ₂ O	...	457	j
23 esculin	H ₂ O(pH ~ 9)	450–470	...	d
24 7-diethylamino-4-methylcoumarin	EtOH	blue	...	d
	EtOH	435–490	...	k
	EtOH	...	460	l
	EtOH	...	460	h
	EtOH	430–490	...	m
	EtOH	439.6–497.0	...	n
25 9-aminoacridine hydrochloride	EtOH (acidic)	...	...	o
	EtOH	455–467	...	k
	EtOH, H ₂ O (acidic)	457–460	...	p
26 4-methylumbelliferone methyl eneimodiacetic acid	EtOH (basic)	459–464	...	o
27 7-acetoxy-4-methylcoumarin	EtOH (basic)	441–486	...	q
28 benzyl- β -methylumbelliferone	EtOH, H ₂ O (basic)	463.5–468	...	p

Table I (Continued).

Dye	Solvent	λ_{nm}	λ_{max}	Ref.
29 calcein blue	EtOH (basic)	449—490	...	o
30 7-methylamino-4,6-dimethyl coumarin hydrochloride	EtOH	470—490	484	b
31 7-ethylamino-4,6-dimethyl coumarin hydrochloride	EtOH	470—490	487	b
32 4,8-dimethyl-7-hydroxycoumarin	EtOH (basic)	...	...	o
	EtOH (basic)	455—505	...	q
33 7-acetoxy-5-allyl-4,8-dimethyl coumarin	EtOH (basic)	458—515	...	q
34 1,3-diphenylisobenzofuran	EtOH	484—518	...	o
	EtOH	484—518	...	k
35 acriflavine	EtOH	...	517.4	a
36 brilliant sulphaflavine	EtOH (neutral)	508—573	...	o
	EtOH	508—574	...	k
37 Na-fluorescein	EtOH, H ₂ O	530—560	...	d
	H ₂ O	...	544	f
	EtOH	...	527	g
	H ₂ O	...	539	g
	H ₂ O	...	550	h
	EtOH	533.6—562.4	...	n
	H ₂ O	...	536	j
	EtOH	...	560	r
	EtOH, H ₂ O	...	550	s
	EtOH, H ₂ O	...	550	t
38 2,7-dichlorofluorescein	EtOH	530—560	...	d
39 6-carboxyfluorescein	EtOH (basic)	539—548	...	o
40 fluorescein	EtOH	...	550	t
	H ₂ O	...	550	t
41 fluorescein diacetate	EtOH (basic)	541—571	...	g
42 3-aminofluoranthene	EtOH	548—580	...	o
43 rhodamine S	EtOH	...	...	o
	EtOH	578—594.5	...	p
44 rhodamine 6G	EtOH	570—610	...	d
	MeOH			
	H ₂ O			
	DMSO			
	PMMA			
	EtOH	...	550	g
	EtOH	...	585	h
	EtOH	...	579	j
	EtOH	565—620	...	k
	EtOH	569.3—609.1	...	n
	EtOH	595—599	...	r
	EtOH	...	585	s
	isoamyl alcohol	...	580	t
	H ₂ O	...	...	...
	PMMA	...	601	u
45 pyronin G	isoamyl alcohol	...	585	t
46 acridine red	EtOH	600—630	...	d
	EtOH	...	593.5	f
	EtOH	...	580	g
	EtOH	...	601.5	h
	EtOH	...	605	j
	EtOH	...	615	r
	EtOH	...	601.5	s
	EtOH	...	610	t
47 rapid-filter gelt	isoamyl alcohol	...	610	t
48 violetrot	isoamyl alcohol	...	610	t
49 rhodamine 3B	isoamyl alcohol	...	610	t
50 rhodamine B	EtOH	605—635	...	d
	MeOH			
	PMMA			
	EtOH			
	EtOH			
	EtOH	...	608	g
	EtOH	...	616	h
	MeOH	...	615	j
	EtOH	589.7—642.7	...	n
	MeOH	...	617	r
	EtOH	...	622	r
	isoamyl alcohol	...	610	t
	PMMA	...	632.4	u
51 lissamine rhodamine B-200	EtOH (neutral)	575—645	...	o

Table I (Continued).

Dye	Solvent	λ_{nm}	λ_{max}	Ref.
52 pyronin Y	EtOH (acidic)	590—635	...	o
53 xylene red B	EtOH (basic)	584—645	...	q
54 kiton red S	EtOH (neutral)	589—642	...	q
	EtOH	595—650	...	k
55 pyronin B	MeOH, H ₂ O	yellow	...	d
	EtOH (neutral)	615—632	...	p
56 cresyl violet	EtOH	646—709	...	o
	EtOH	645—709	...	k
57 pyrylium salt	MeOH	green	...	d
58 acetamidopyrene-trisulphonate	MeOH, H ₂ O	yellow-green	...	d
59 1,3,3,1',3',3'-hexamethyl-2,2'-indotricarbocyanine iodide	acetone	...	800	a

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Reproducible Preparation of Homogeneous In_{1-x}Ga_xP Mixed Crystals

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(Received 6 August 1971)

A solution-growth method was developed to obtain highly homogeneous In_{1-x}Ga_xP mixed crystals. In this method, a GaP crystal was the source material which was placed in the high-temperature portion of the In solution. An In_{1-x}Ga_xP mixed crystal of a controlled composition crystallized in the low-temperature portion of the solution. The temperature of the solution and the vapor pressure of phosphorous were maintained constant in order to obtain mixed crystals of a high homogeneity. An x-ray analysis showed that the mixed crystals thus prepared were uniform within 0.01-mole fraction.

In_{1-x}Ga_xP is a highly attractive material for its large direct band gap which is attainable with a composition of x within 0.6–0.8.¹⁻³ However, it is difficult to obtain homogeneous In_{1-x}Ga_xP mixed crystals from

a solution, particularly when $x < 0.9$, since the liquidus composition of the In-Ga-P system varies as the crystal grows. Recently, Rodot *et al.*¹ and Burnham *et al.*⁴ prepared In_{1-x}Ga_xP mixed crystals