SPATIAL RESOLUTION IN THERMAL RECORDING OF OPTICAL IMAGES ON THIN FERROMAGNETIC FILMS

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To determine the resolving power of the thermal method of recording optical images on thin ferromagnetic films (TFF) with strip domains [1], the following experiment was performed: An image in the form of long light strips, 60 μ wide, was projected on a permalloy film (82% Ni - 18% Fe) of thickness h = 8000 Å on a glass substrate. A rotating magnetic

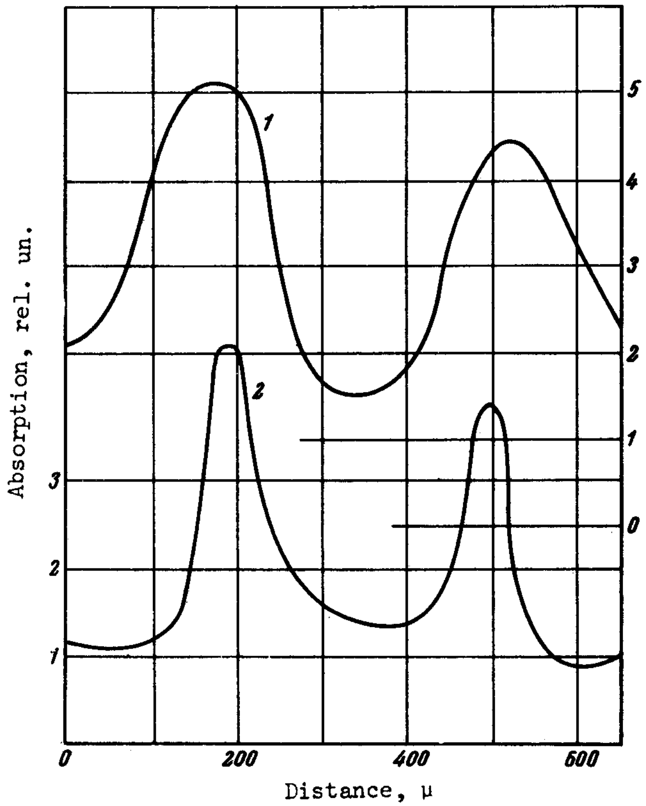


Fig. 1

field 5% lower than the starting value [2] was applied in the plane of the film at an angle 90° to the initial domain orientation. A magnetic colloid was coated on the surface of the film to make the recorded image visible. The observation was made in white light at the angle of diffraction of green light by powder figures duplicating the domain structure of the film on its surface [3, 4]. The role of the optical image was played by a ruby-laser beam passed through a multiple-slit stencil.

Figure 1(2) shows a microphotograph of the image obtained after illuminating a ferromagnetic film by a pulse of 30 nsec duration (pulse energy 0.02 J). Such an exposure satisfies the condition for adiabatic heating of the image elements (light bands) and the resolution does not depend on the thermal relaxation. The width of the bands on the image is close to the initial value 60 μ. The resolving power, which is governed in this case only by the structural properties of the film, reaches a value on the order of 10^{-3} cm. In the case of longer exposure, a spreading of the temperature waves takes place as a result of the diffusion of the heat through the film and substrate, and the higher spatial harmonics of the image are suppressed. The distortions due to this effect can be estimated with the aid of the formulas presented below.

We represent the specific power of radiant heating q (W/cm^3), averaged over the film thickness, in the form of the series

$$q = (e^{-\beta_1 t} - e^{-\beta_2 t}) \sum_{n=0}^{N} q_n \cos\frac{2\pi n x}{D}; \quad q_0 \gg \sum_{n=1}^{N} q_n ,$$

where D is the dimension of the film in the direction of the x axis and D/n is the period of the n-th harmonic of the image. The film is in thermal contact with a bulky glass substrate, and is also cooled by the surrounding air, with a heat-exchange coefficient $\mathcal{H}$. The illumination is produced by a pulse whose time plot has a bell-shaped form $f(t) = \exp(-\beta_1 t) - \exp(-\beta_2 t)$; $\beta_2 > \beta_1$; $t \geq 0$. Neglecting the thermal resistnace of the film in the direction of its thickness (z axis), we obtain the solution of the system of heat-conduction equations and the temperature distribution function in the film:

$$v(x, t) = \frac{1}{c_1 \gamma_1} \sum_{n=0}^{N} \sum_{l=1,2} (-1)^{l-1} q_n \cos\frac{2\pi n x}{D} \exp\left(-\frac{t}{\tau_{2n}}\right) \times$$

$$\times \sum_{l=1,2} \left\{ C_{ln}^{(l)} \exp\left(\frac{t}{\tau_{2n}} - \beta_l t\right) \operatorname{erfc}\left[(-1)^l \sqrt{\frac{t}{\tau_{2n}} - \beta_l t}\right] + \right. \tag{1}$$

$$\left. + D_{ln}^{(l)} \exp\left(\frac{t}{T_{ln}}\right) \operatorname{erfc} \sqrt{\frac{t}{T_{ln}}} \right\},$$

where the coefficients are given by

$$T_{1n,2n} = \left(\frac{\lambda_2}{2hc_1 \gamma_1 \sqrt{a_2}} \pm \sqrt{\frac{\lambda_2^2}{4h^2 c_1^2 \gamma_1^2 a_2} + \frac{1}{\tau_{2n}} - \frac{1}{\tau_{1n}} - \frac{\mathcal{H}}{hc_1 \gamma_1}}\right)^{-2}; \tag{2}$$

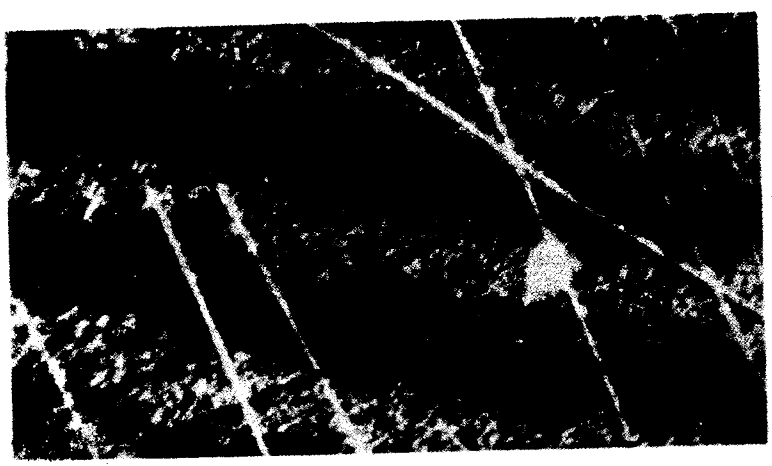
$$C^{(l)}_{1n,2n} = \frac{h}{2} \left[\left(\frac{1}{\tau_{1n}} - \beta_l\right) h + \frac{\mathcal{H}}{c_1 \gamma_1} \pm \frac{\lambda_2}{c_1 \gamma_1 \sqrt{a_2}} \sqrt{\frac{1}{\tau_{2n}} - \beta_l}\right]^{-1}; \tag{3}$$

$$D^{(l)}_{1n,2n} = \pm 4C_{1n}^{(l)} C_{2n}^{(l)} \frac{T^{-1}_{2n,1n} - \tau^{-1}_{2n} + \beta_l}{T_{2n}^{-1/2} - T_{1n}^{-1/2}} T^{-1/2}_{1n,2n}; \tag{4}$$

$$\tau_{1n,2n} = \frac{D^2}{4\pi^2 n^2 a_{1,2}}; \tag{5}$$

γ_1, γ_2 - density, c_1, c_2 - specific heat, λ_1, λ_2 - thermal-conductivity coefficients, and σ_1, σ_2 - temperature conductivities of the film and substrate, respectively.

The solution (1) - (5) determines the following characteristic times: 1) $T_{2n} \approx (hc_1\gamma_1)^2 \times (c_2\gamma_2\lambda_2)^{-1}$ - for the diffusion of the heat from the film to the interior of the substrate; when h = 5000 Å we have T_{2n} = 2 μsec. 2) τ_{2n} - for the diffusion of heat in the x-axis direction, primarily through the substrate when $D/n > 2 \times 10^{-2}$ cm. 3) T_{1n} - for the combined relaxation of the temperature waves in the x direction through the film and through the substrate when $2 \times 10^{-2} > D/n > 5 \times 10^{-3}$ cm. 4) τ_{1n} - for the predominant relaxation in the x direction inside the film when $D/n < 5 \times 10^{-3}$ cm. Putting $D/n = 1.2 \times 10^{-2}$ cm, we get T_{1n} = 0.4 msec. Consequently, illumination with a millisecond pulse suppresses the higher harmonics strongly, and the resolving power does not exceed a value on the order of 1×10^{-2} cm. This theoretical result is confirmed experimentally. The image was duplicated on a region of the film which was specially obscured in the first experiment using a laser pulse duration 1 msec, which is much larger than T_{1n} (pulse energy 0.5 J). On the corresponding microphotograph of Fig. 1(1), the lines are "smeared" to a width ~150 μ, in accord with Eq. (1). Figure 2 shows an interference pattern recorded on a thin magnetic



film with the aid of a Fresnel biprism, using illumination with a 30-nsec pulse of a ruby laser. The width of the fringes on the interference pattern, which equals the width of the slits of the stencil in the preceding experiment, is 60 μ.

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