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MICRO-MACHINED SILICON BOLOMETERS AND THERMAL EMITTERS

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Technology of micro-machined silicon bolometers and thermal emitters of infrared radiation operated in gas filled packages has been developed. Bolometers exhibit detectivity of 10^8 cm Hz $^{1/2}$/W at frequency 20Hz. Emitters exhibit integral luminance of 10 mW/(mm^2 srd) with a spectral peak at the wavelength of 4 μm.

Technology of micro-machined silicon bolometer and thermal emitters of infrared radiation operated in gas-filled packages has been developed. The devices are based on ≈1 μm polysilicon/Si_3N_4 membrane suspended over a cavity. This has been achieved by anisotropic etching of silicon with previously deposited polysilicon/Si_3N_4 sandwich. Alternatively, porous silicon as the sacrificial layer was been used.

Lightly doped polysilicon has been selected as the thermoresitive material. Although some materials such as VO_2-based layers exhibit higher temperature coefficient of resistivity (TCR); polysilicon offers advantages of low cost and well established technology. In contrast to the high TCR materials, polysilicon microbolometers can operate in a wide range of temperature.

The first step in preparation of microbolometer is to cover the silicon wafer with 0.2-1.5 μm thick silicon nitride layer using plasma enhanced chemical vapor deposition (PECVE). Next, 0.1 -1.5 μm thick silicon layer is deposited using RF sputtering. To increase conductivity the layer is doped by boron implantation with ion dose of $(3\times10^{12}$-$5\times10^{14})$ cm^{-2} and energy of 20 keV. Activation of dopant is achieved by rapid thermal anneal. The annealing causes recrystallization of amorphous silicon converting it into polycrystalline material. The resistivity of polysilicon is a complex function of crystallite grain size, doping concentration and temperature. It can be controlled by implantation dose and conditions of thermal anneal. Typically, layers with sheet resistivities of (300-900) kΩ/sqr and TCR of ≈2%/K were used for.

Al contact pads are deposited by e-beam evaporation. Patterning of metallization and silicon layers is accomplished with photolithography. The cavity is then formed by selective etching of silicon substrate. To obtain the bottom reflector 50 nm metal layer is prepared by sputtering of tungsten or nichrom onto backside of silicon nitride through the holes etched off in silicon wafer. The structures are then epoxed to 300 μm thick silicon wafer. The wafers are cut with diamond saw into individual devices.

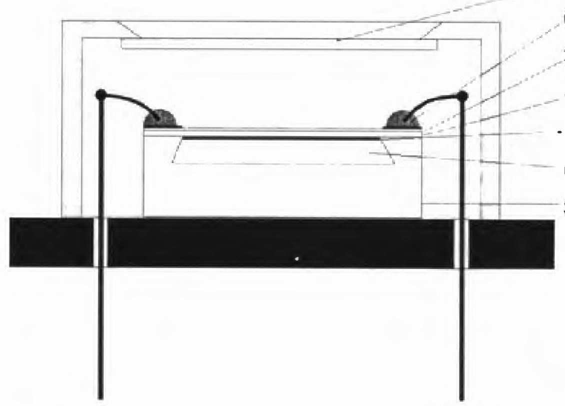

Fig. 1. Schematic cross-section of a single element silicon microbolometer or thermal emitter.

Fig. 1. shows schematic cross-section of a single microbolometer. The active chip of microbolometer was mounted on the TO-baseplate base using thermally conductive epoxy. Although vacuum provides the best thermal insulation, the reliable vacuum packaging is complex and expensive. Therefore, gas packaging is of choice in many cases.

The packaging is completed by mounting a transistor cap with IR transparent window onto the base. The hermetization is desirable even for devices operated in air. This prevents interferences cased by air convection. BaF_2, ZnSe, sapphire, AR-coated Si and Ge, and other window materials have been used. The housings were evacuated and then backfilled with dry air, Xe or Xe-Kr mixture. Hermetized has been achieved using epoxy.

Typically, the responsivities at low frequencies of devices operated at inert gases were by a factor of ≈4 larger compared to that for devices operated in air. Fitting the experimental voltage responsivities with theoretical curve makes possible to determine emissivity, time constant and thermal capacity. The emissivity of various devices ranged between 0.2 and 0.9 as a function of wavelength, silicon doping, thick-

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nesses of silicon, Si_3N_4 and W layers. This was a result of absorption of radiation in the layers, modified by the interference due to internal reflections in the structure. The time constants ranged from 1 to 7 ms for devices operated in air. Thermal capacitance per unit of area was dependent on thickness of the silicon and silicon nitride layers, ranging from $4\times10^{-5}\,JK^{-1}cm^{-2}$ to $\approx2\times10^{-4}JK^{-1}cm^{-2}$. This can be reduced using thinner membranes and silicon layers and improve performance at high frequencies.

Detectivities up to $10^8\,cmHz^{1/2}/W$ were measured at low frequencies (≈20 Hz) for the best devices operated in Kr-Xe mixtures. The detectivity decreases with increasing frequency due to decreasing voltage responsivity. The decrease of voltage responsivity is, in some degree, compensated by the excess noise reduction.

Similar micromachined bridge structures has been used for thermal microemitters of infrared radiation. Much stronger doping has been used to obtain sheet resistances of ≈1 kΩ/sqr. This was necessary for low voltage power supply to few volts. Another advantage of high doping is a low TCR. The devices exhibited integral luminance of 10 $mW/(mm^2srd)$. The spectral luminance peaked in the range of 3-5 μm with values higher than that achieved with ≈4 μm LEDs operated at room temperature. The shape of spectral luminance can be modified by selecting thickess of the Si, Si_3N_4 and W layers to establish resonant optical resonance in required spectral range. The response time was 1-4 ms, decreasing with increased bias. This enables to modulate luminance changing electrical bias.

Improved performance and reliability with the reduced cost associated with silicon micromachining technology and compatibility with standard IC make the bolometers and thermal emitters attractive for many high-volume civilian and military applications, such as non-contact thermometry, gas analyzers, exhaust-emission controls and medical monitor instrumentation.

Short biography note

Józef Piotrowski received his PhD in 1973 from Military University of Technology, Warsaw, Poland. His scientific interests concern semiconductor physics and technology, IR physics, microelectronics and optoelectronics. He was engaged in the research and design of infrared photodetectors based on II-VI and III-V narrow gap semiconductors. He has developed and introduced into practice many types of novel IR photodetectors operating without cooling. Currently he is a development manager of VIGO SYSTEM Ltd. Warsaw. Author or co-author of about 200 papers and monographs on infrared photodetectors.

Lech Dobrzański was born in Starachowice, Poland, in 1951. He received M.Sc. degree from Warsaw Technical University in 1974. From 1974 to 1988 he worked in Scientific & Production Center CEMI. He was involved as a leader of the technological team in a project of LEDs on GaAsP (from 1974 to 1979). The successful set up of production line was awarded in 1978. From 1980 to 1985 he was involved in a project of polish microprocessor chip. Project was completed in 1984 and awarded. From 1995 to 1988 he worked at CEMI as a designer of bipolar integrated circuits. In 1988 he joined ITME. Here he was involved in organization of a laboratory for making semiconductor devices on $A_{III}B_V$. In 1994 he received Ph.D. degree from ITME. His research interests include modelling of technology, modelling of semiconductor devices and ICs.